SEWAGE AND INDUSTRIAL WASTES

JOURNAL of the FEDERATION OF SEWAGE AND INDUSTRIAL WASTES ASSOCIATIONS

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APRIL 1958—VOL. 30, No. 4

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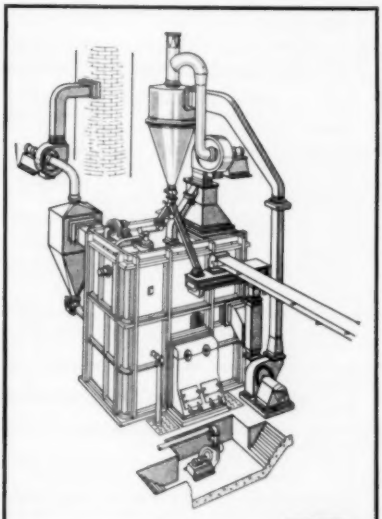

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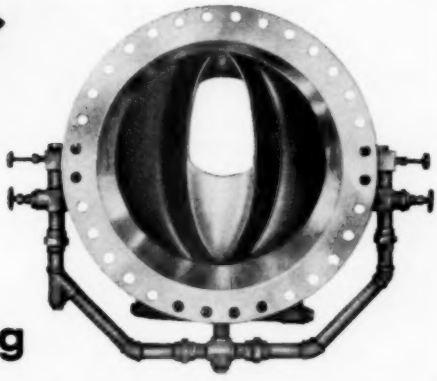

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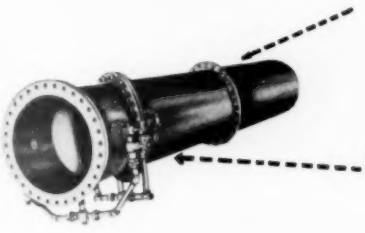

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Association	*Place*	*Time*
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Central States Sewage and Industrial Wastes Assn.	Purdue Univ. Lafayette, Ind.	May 5–7, 1958
Arizona Sewage and Water Works Assn.	El Conquistador Hotel Tucson, Ariz.	May 15–17, 1958
Sweden (Foreningen for Vattenhygien)	Consert Hall Oerebro, Sweden	May 16–17, 1958
New York Sewage and Industrial Wastes Assn.	Grossinger Hotel Catskills, N. Y.	May 26–27, 1958
Alabama Water and Sewage Assn.	Alabama Poly. Inst. Auburn, Ala.	June 4–6, 1958 (*Revised Date*)
New England Sewage and Industrial Wastes Assn.	Colonial Hotel Gardner, Mass.	June 4–5, 1958
Ohio Sewage and Industrial Wastes Treatment Conf.	Commodore Perry Hotel Toledo, Ohio	June 18–20, 1958
Iowa Sewage and Industrial Wastes Assn.	Hotel Chieftan Council Bluffs, Iowa	June 18–20, 1958
Michigan Sewage and Industrial Wastes Assn.	Charlevoix Hotel Charlevoix, Mich.	June 23–25, 1958
Institute of Sewage Purification	Floral Hall Southport, England	June 24–27, 1958

THIRTY-FIRST ANNUAL MEETING

Federation of Sewage and Industrial Wastes Associations
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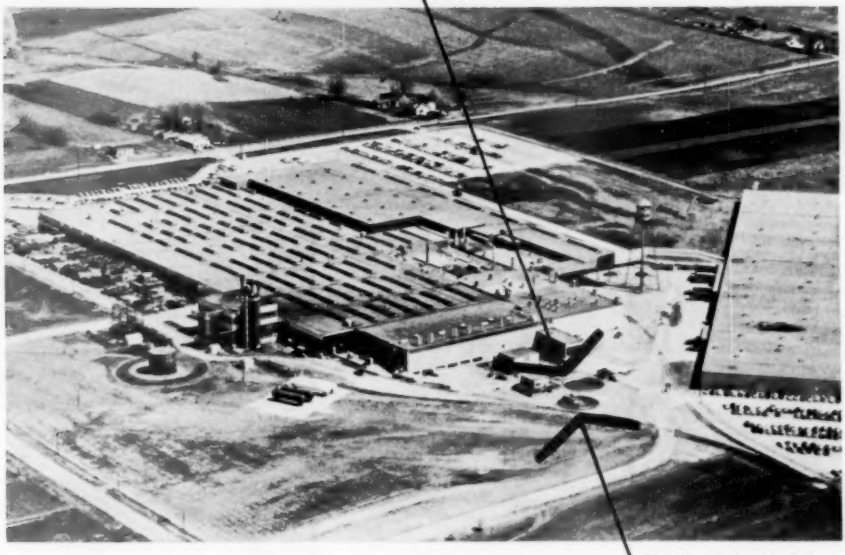

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Chicago, Illinois	36"	7,200	2.6-3.6	New	147
New Orleans, La.	12"	39,650	1.2-2.9	New	141
Carder, Mo.	8"	21,350	0.9-2.3	New	143
Univ. of Illinois	8"	400	3.14	New	150
Concord, New Hamp.	14"	500	1.7-2.2	New	151
Concord, New Hamp.	12"	500	2.0-3.4	11	142
West Palm Beach, Fla.	12"	500	3.6-5.4	15	139.5
Greenville, S. C.	30"	87,376	2.4-2.7	12	148.5
Corpus Christi, Tex.	30"	65,641	1.1-1.8	6	146
Summerville, S. C.	8"	500	1.98-2.43	13	142.5
Champaign, Illinois	16"	3,920	3.1-5.6	22	139.3

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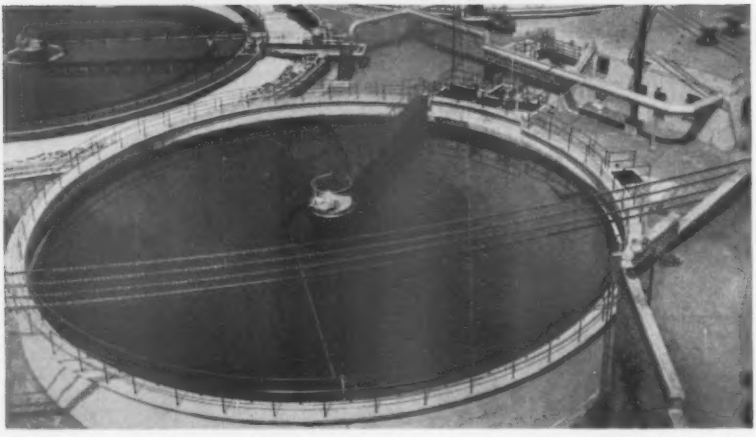

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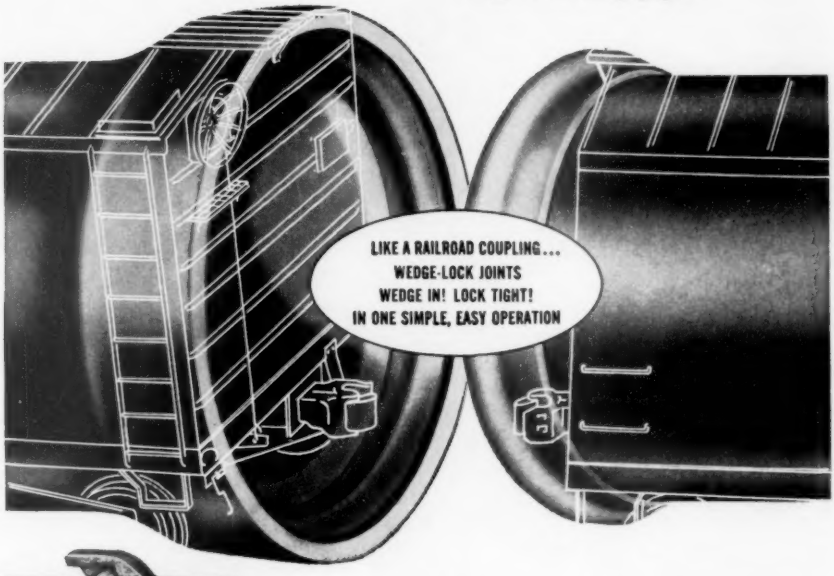

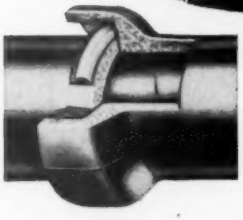

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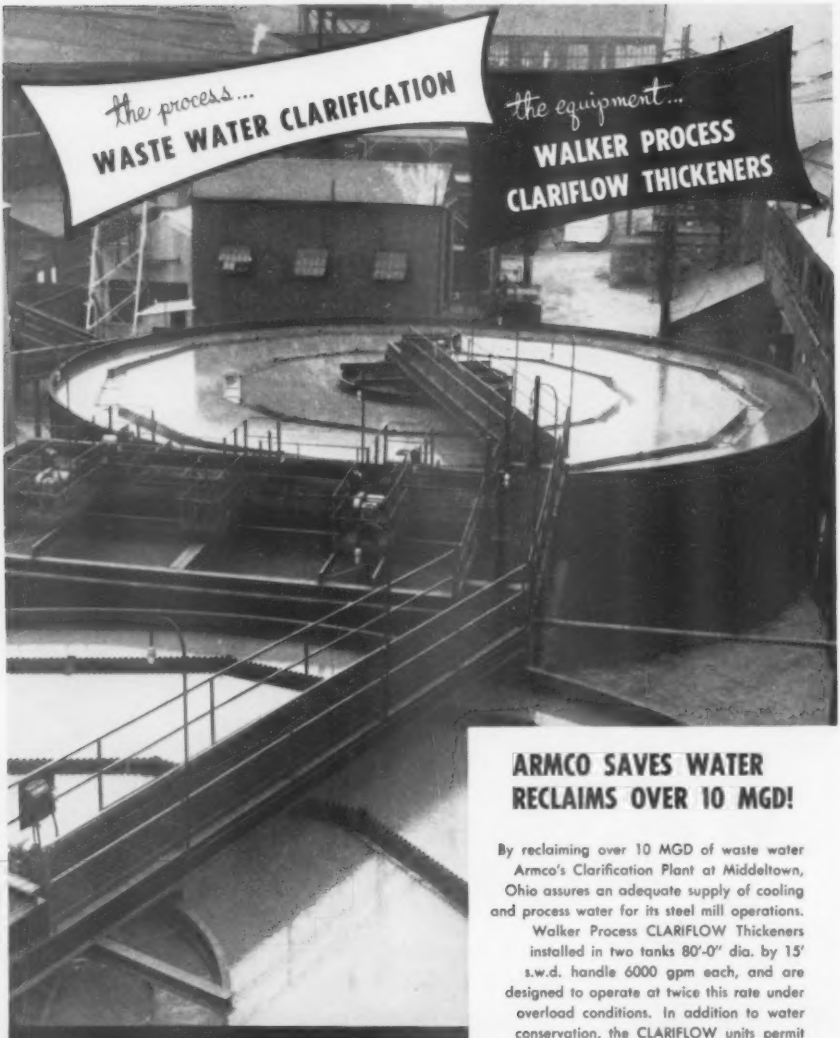

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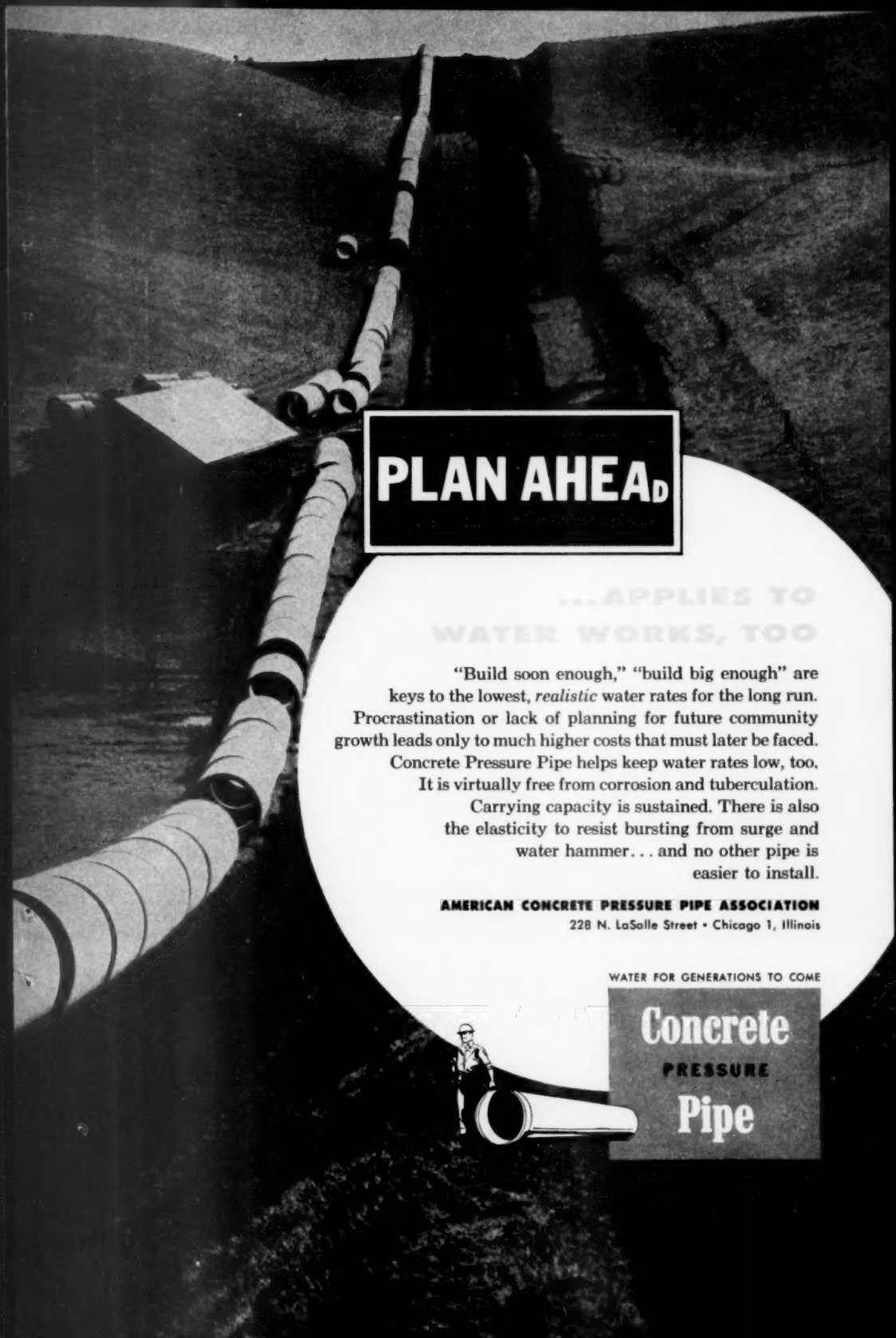
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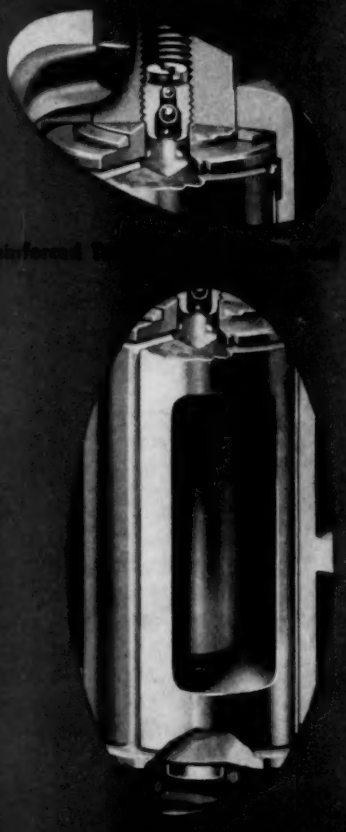

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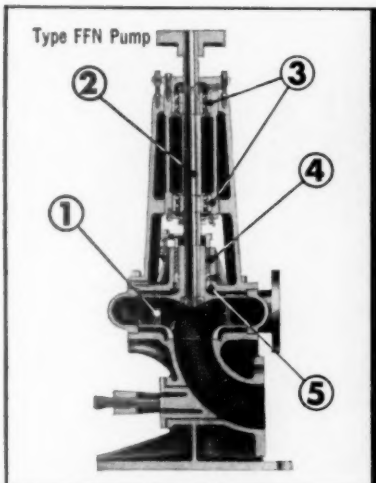

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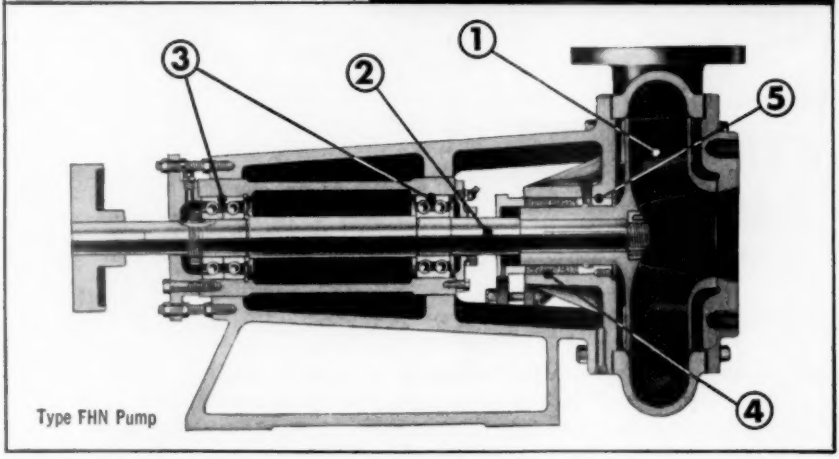

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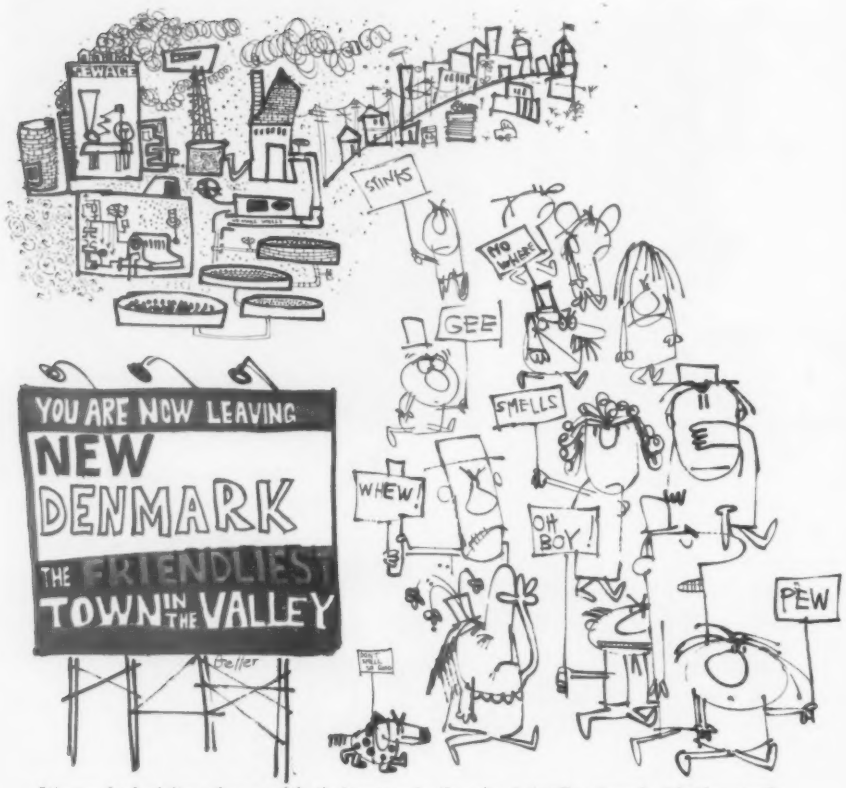

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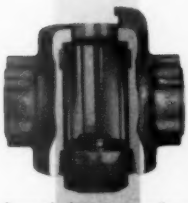
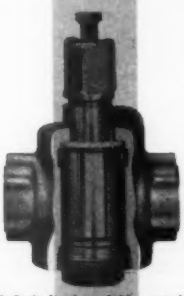


Smooth bearing-surface in body



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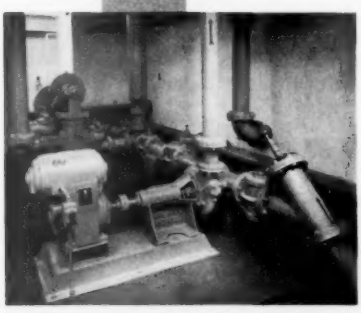

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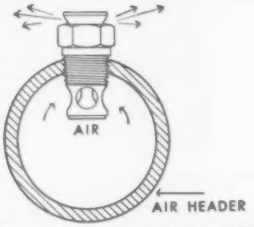

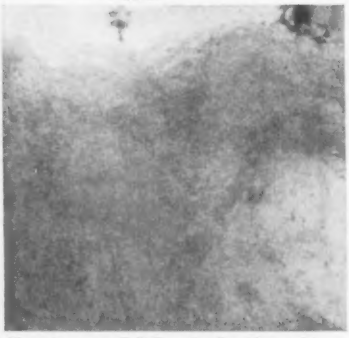

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Journal of the Federation of Sewage and Industrial Wastes Associations

Volume 30 | **April 1958** | **Number 4**

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Sewage Works

REDOX POTENTIALS IN WASTE TREATMENT—LABORATORY EXPERIENCES AND APPLICATIONS *

By Werner N. Grune and Chun-Fei Chueh

Associate Professor and Research Associate, respectively, School of Civil Engineering, Georgia Institute of Technology, Atlanta, Ga.

For a number of years, the application of oxidation-reduction potential measurement has been proclaimed by a number of investigators as a new parameter in the analysis and control of waste treatment processes (1) (2) (3). Nevertheless, the profession has been slow to grasp and utilize the oxidation-reduction potential concept. It has been especially difficult to recognize and accept this term in connection with anaerobic fermentations or sludge digestion. Since bio-oxidation or respiration must furnish the energy for the life process of both aerobic and anaerobic organisms, oxidation in biological systems must be redefined to include all chemical reactions which liberate energy that is available to the living cell.

As a result of Pasteur's fundamental studies on fermentation in the absence of air, the concept was established that living organisms were not confined to obtaining their energy through conventional respiratory functions, and "respiration" has been used to express any exothermic reactions involving a transfer of energy value for growth activities whether or not free oxygen and a respiratory organ were involved. In speaking of cellular respiration it has therefore become customary to use the term bio-oxidation, and its chemical connotation is quite broad to include both aerobic and anaerobic respiration (4).

Use of oxidation-reduction potential measurement as a parameter during aerobic treatment of wastes has been advocated for years and has recently found more general acceptance. Examples are in the treatment of industrial wastes, in the activated sludge process, and for final effluent control (5)(6)(7)(8)(9)(10). The fermentation industry has also realized the value and benefits which can be derived from redox potential measurements, together with pH and conductivity control. However, in the anaerobic phase of waste treatment—the ultimate disposal of the sludge—this control procedure has received relatively little attention. There are indications that this can be a dependable tool to those in the sanitary engineering field. However, a word of caution is needed. The tool is no better than its user and intelligent application requires a profound understanding of the underlying principles and the circumstances under which the measurements are made.

The theory and measurement of redox potentials are not new; Clark (11), Clark and Cohen (12), Michaelis and Smythe (13), Hewitt (14), and Glasstone and Hickling (15) helped to build

* Presented at the 1957 Annual Meeting, Pennsylvania Sewage and Industrial Wastes Assn.; University Park, Pa.; Aug. 28–30, 1957.

the foundation for present-day interpretation of the fundamental concepts. However, application of the theory and its translation into practical use by the sanitary engineer and plant operator began only a decade ago and the profession is only at the threshold of the full evaluation and appreciation of the significance of redox potentials in waste treatment.

As will be shown later, a number of difficulties remain unsolved; but as knowledge increases, experimental conditions become better controlled, and commercial equipment is improved, these difficulties will eventually be overcome. Although it is true that the O-R potential equipment has been fairly well standardized, the electrodes and the manner in which the potential is measured leave room for more improvement. In measuring the potential of a complex heterogeneous mixture such as activated sludge, or digesting sludge, where many oxidizing and reducing systems, both reversible and irreversible, exist, such a measurement presents only an over-all picture. It is axiomatic, therefore, that in measuring such activity of a biological complex the results yield no answer to any particular system.

Theoretical Considerations

Based on the general definition of the oxidation-reduction process, an oxidation involves a loss, and a reduction a gain, of one or more electrons. A typical example is the hydrogen electrode, where the hydrogen gas is the reduced and the hydrogen ion is the oxidized form.

The oxidation-reduction potential is a measure of the tendency for a substance to give up or to accept electrons. In other words, it is a quantitative measure of the free energy of the reaction involved in the electronic transfer. During the metabolic process of microorganisms, a definite oxidation-reduction potential is maintained in a particular organism-substrate system, the reduction intensity of which depends on the species, cultural age, its variation phase, and its environment (14). The value of O–R potentials in characterizing a physiological state in higher forms of life has been established. The relationships between reduction intensity and known physiological conditions have already proven of special value in bacteriology.

The transfer of an electron or electrons from one compound to another is a result of potential difference between the two reactants. Because these reactions always involve electron transfers it is possible to study them by means of potentiometers, capable of measuring electrical potentials. The magnitude of this potential difference depends upon the ease with which the electrons are lost or gained. The greater the oxidizing or reducing power of a substance, the greater will be the electrical potential difference. The O–R potential is always referred to the normal hydrogen electrode, which is assumed to have zero potential. The more highly oxidizing a substance, the more positive will be its electrical potential; the more highly reducing a substance, the more negative will be its electrical potential.

The direction in which a reaction proceeds is dependent on the free electrons in the system. If the number of electrons is increased, the system will produce more of the reductant; if the number is reduced, the system will produce more of the oxidant. The electronic state of the system is a measure of its oxidizing or reducing power.

The O–R potential of a system, referred to the hydrogen electrode, is expressed by the symbol E_h. The greater the proportion of reduced substance present, the lower will be the E_h value; conversely, the greater the proportion of oxidized substance, the higher will be the E_h value. When the molar concentrations of oxidant and reductant are equal, the term E_h becomes equal

to E_0. Thus,

$$E_h = E_0 + \frac{R\,T}{n\,F} \ln \frac{[\text{Ox}]}{[\text{Red}]} \ldots (1a)$$

$$E_h = E_0 + \frac{k}{n} \log \frac{[\text{Ox}]}{[\text{Red}]} \ldots (1b)$$

in which

E_h = the measured electrode potential, in volts, in reference to the standard hydrogen electrode;

E_0 = a standard potential of the system when the activities of all oxidants and reductants are unity and at 30° C;

$k = \dfrac{R\,T}{2.303F}$;

R = 8.315 volt-joules coulombs (the gas constant);

T = the absolute temperature in ° K;

F = 96,500 coulombs; and

n = the number of electrons that participate in the potential system.

Taking into account the difference between common and Napierian logarithms, $\ln x = 2.3026 \log x$, the value of the constant $k = \dfrac{R\,T}{2.303F} = 0.06011$ at 30° C.

In biological oxidation, two kinds of reactions may be distinguished as typifying anaerobic and aerobic oxidations (4):

1. Loss of hydrogen (dehydrogenation, anaerobic, common).

$$\underset{\text{(ethyl alcohol)}}{C_2H_5OH} - 2H \rightarrow \underset{\text{(acetaldehyde)}}{C_2H_4O} + \underset{\text{(oxidiz. agent)}}{H_2} \ldots (2)$$

Hydrogen combines with some oxidizing agent (acceptor) such as atmospheric oxygen or other reducible substance. An electron is transferred at the time hydrogen is transferred, thus an energy transfer is involved.

2. Addition of oxygen (aerobic, uncommon).

$$CO + \tfrac{1}{2}\,O_2 \rightarrow CO_2 \ldots\ldots (3)$$

Factors Affecting Redox Potentials

It may be assumed that in future years the instrumentation for potential measurement will be so vastly improved that present techniques may be compared to the crude hydrogen electrode used at the turn of the century. Nevertheless, as will be shown later, measurements can be obtained with reproducibility within 5 to 10 mv.

There are, however, a number of conditions affecting the potential as well as the rate of change of a potential in a biological medium. The more influential factors, as aptly summarized earlier by Rohlich (16), are as follows:

1. The ratio of the concentration of the oxidant to that of the reductant.
2. The temperature of the solution.
3. The tendency of the system to take up or give off electrons.
4. The hydrogen ion concentration.

It has been clearly pointed out in the literature (11)(14), that redox potential is a measure of the intensity and not of the capacity of a system. This makes O–R potential determinations analogous to pH and temperature readings. Because O–R potential is not an indicator of the ability to oxidize or to reduce, this is left to the "poising effect," similar to the term "buffer action," used in pH work.

The ratios of concentrations of oxidant to reductant, when dealing with sewage or industrial wastes, lose their real meaning, inasmuch as the myriads of reactions which simultaneously occur cannot be described in one over-all reaction. This is in contrast to the chemist who is certain of the reactions—a difficulty to which the sanitary chemist and engineer must become accustomed. However, the usefulness of the O–R potential as a parameter, as long as it is properly interpreted, is therefore not diminished.

The hydrogen ion has a measurable effect on the redox potential. For illustration, consider a simple oxidation-

reduction reaction:

$$R^- \leftrightharpoons O_x + e \quad \ldots\ldots (4)$$

where R^- is a reductant with one negative charge and O_x is an un-ionized oxidant. According to Eq. 1*a*, at equilibrium state

$$E_h = E_0 + \frac{RT}{nF} \ln \frac{[Ox]}{[Red]} \quad \ldots (1a)$$

But the anion R^- reacts with hydrogen ion existing in solution as follows:

$$H^+ + R^- \leftrightharpoons HR \quad \ldots\ldots (5)$$

Therefore, at equilibrium the concentration of R^- in solution is governed by the concentration of hydrogen ion in the same solution through the usual mass action equation

$$\frac{[H^+][R^-]}{[H\,R]} = k_d \quad \ldots\ldots (6)$$

Combining Eqs. 1*a* and 6 gives

$$E_h = E_0 + \frac{RT}{F} \ln \frac{[O_x][H^+]}{k_d\,[H\,R]} \quad \ldots (7)$$

Eq. 7 shows that E_h is a function of $[H^+]$. If both the reduced form and oxidized form are ionized, or polyvalent ions are formed, the expression becomes very complicated. Although at one time Clark advanced the concept of rH, in which he assumed that there is a known simple relationship, he later rightfully insisted that the use of this term should be discontinued. If proper interpretations and the results from potential measurements are to be made, it is therefore necessary that pH values be simultaneously obtained.

The factors affecting potential measurements may be summarized by stating that they depend on three conditions at a fixed O-R potential:

1. The innate tendency of a system to take up or to give off electrons.
2. The ratio of the oxidant to the reductant.
3. The hydrogen-ion concentration.

The role of temperature will be discussed later.

Mechanisms Underlying Biological Oxidations

In addition to the inorganic conditions affecting the potential of a system, Eckenfelder (9) pointed out the important role played by microorganisms in the potential measurement of wastes. The more important factors are as follows:

1. The kinds of organisms present.
2. The condition of the organisms.
3. The growth phase of the mass.
4. The nature of the constituents and their quantities in the system.
5. The conditions of the operation.

In the classification of organisms according to metabolism and respiratory requirements it is possible to distinguish between autotrophic, saprophytic, and parasitic, or pathogenic, bacteria.

Autotrophic bacteria obtain their energy from inorganic oxidation of compounds, such as NH_3, NO_2^-, H_2, $S^=$, CNS^-, Fe^{++}, and utilize inorganic carbon and nitrogen compounds for building complex organic compounds. These are common soil and water organisms.

Heterotrophic bacteria include saprophytic and parasitic organisms. Saprophytic organisms are those which utilize more complex organic food materials, such as the dead bodies or waste products of other organisms. Putrefying animal bodies, feces, plant and animal matter in soil contain large numbers of these organisms. Most of the bacteria of this group are economically important in reducing complex dead organic matter to simple soluble compounds for availability to plants and bacteria.

Parasitic bacteria are present only in living organisms and, therefore, are of no importance in the degradation of dead organic matter.

Aerobic and Anaerobic Metabolism

Since oxidation serves as a source of energy, it might be thought that all bacteria require free oxygen. For aerobic organisms this is true; they

cannot get along without free access to air. *Pseudomonas fluorescens* and *Bacillus subtilis* are of this type. Other species, such as *Actinomycetes, Bacteroides,* and *Clostridium,* not only are able to grow without free oxygen, but will grow only in the absolute absence of atmospheric oxygen. They are called "strict" or "obligate" anaerobes.

Between these two limits, the great majority of bacteria live under facultative conditions. They can utilize atmospheric oxygen and can also proliferate quite well without free oxygen, using combined oxygen for respiration. These are the facultative aerobes and anaerobes. Common species, facultative in respect to oxygen, include *Escherichia coli, Streptococcus lactis,* and *Staphylococcus aureus.*

Later sections of this paper will refer to the type and condition of organisms, the growth phase, the nature and concentrations of the biological, bacterial and biochemical constituents, all of which play their important role in the potential measurement of wastes.

The physiological systems carrying the various types of exothermic reactions to completion are complex and include the respiration enzymes, coenzymes, and other coadjutant bodies. Chemically, the enzymes have been identified as proteins. The most important respiration enzymes are dehydrogenases, phosphorylases and oxidases. Dehydrogenases do not make use of molecular oxygen as they transfer hydrogen to a hydrogen carrier. After intermediate steps the hydrogen is transported to oxygen or other H_2-acceptors. The anaerobic dehydrogenases may result in the formation of H_2S and CH_4.

The coenzymes and other auxiliary agents, such as the coenzymes I and II (DPN and TPN), thiamin pyrophosphate, and iron porphyrin flavins, are hydrogen carriers, readily reduced by accepting hydrogen and oxidized by yielding hydrogen. All are involved in oxidation or reduction processes, or both. For a further treatment of this vital subject matter the reader is referred to a number of excellent references (17)(18)(19)(20).

In connection with a number of the previously cited conditions affecting the potential, several factors have been found which appear to be of particular importance in relation to potential measurement during anaerobic fermentation, if not equally important for potential measurements of other waste treatment processes. These are:

1. Length of time allowed for stabilized potential measurement.
2. Temperature of the system to be measured.
3. Value of flow-through cells to obtain continuous long-range potential measurements without polarization.

These factors, and their evaluation, and means to overcome problems as far as has been possible, serve as the basis for this paper.

Purpose of Redox Potential Measurement

A statement on why redox potentials are used and what value is to be expected in applying the potential measurements in anaerobic waste treatment is in order.

It has been possible to obtain reproducible measurements of gas production and to formulate mathematically the anaerobic digestion process as a first-order or autocatalytic curve expressed in relatively simple terms such as a reaction velocity constant k, and ultimate gas production L. These have served and will continue to serve as useful parameters in waste treatment. The measure of the rate of volatile matter reduction has been a useful yardstick in comparing digester performances, as well as the evaluation of information regarding the production and presence of volatile acids for maintaining operating conditions. Analyses of the solids concentration, pH, grease,

and scum content, have often provided much additional information.

It has not been possible, however, to measure the conditions prior to gas production, acidification, etc. All results in terms of the usual and conventional parameters, therefore, represent a fragmentary picture. They tell nothing about the direction or the intensity of the reactions proceeding in the fermentation process. This is where the redox potential comes into the picture. The data shown demonstrate that acidification and gas production may be expected after certain changes in redox potential have been noted. This provides sufficient advance notice, which in plant operation would be a most valuable insight into the process not presently available to the operator. Furthermore, the entry of certain industrial wastes of strong reducing or oxidizing power can almost instantaneously be indicated to the operator by one glance at a recorder, making it possible to shift operation before any real damage has been done.

Specific Application in Radioactive Waste Studies

The primary purpose of interest in the measurement of redox potentials in sewage and wastes undergoing anaerobic digestion is to have an additional parameter which reflects the effect of radioactive materials on anaerobiosis. Although the full development of redox potential in this area may come at a later date, some of the information obtained from these studies may be a contribution to the general fund of knowledge.

Measuring Systems

A measuring system for redox potential consists of a standard half-cell and an inert, noble metal electrode (that is, platinum, gold, etc.). Both electrodes are immersed in the sludge, or the sludge is pumped through the cell; the latter method is used to prevent poisoning and polarization. The former is referred to as the stationary cell, and the latter as the "flow-through" cell. Both types of cells have been employed in the studies reported herein.

Stationary Cell

There are three kinds of measuring meters available in the laboratory for the stationary type of cell—the Beckman pH potentiometers Model H–2, G, and WM. All employ a saturated calomel half-cell and a platinum electrode.

Although their potential readings agree between each other within ± 2 per cent when a standard quinhydrone solution is measured, the Model WM appears to be preferable over the Model G in the determination of O–R potentials for anaerobic sludges. This is because the 14-cm long electrodes can be immersed relatively deep into a large sample (1-l beaker or more) to avoid diffusion of atmospheric oxygen into the anaerobic sludge during measurement. For the measurement of O–R potential of colloidal solutions, such as sludges, the Model H–2 appears adequate only if its fiber-type calomel half-cell is replaced by a sleeve-type cell (as the fiber in the immersion end of the electrode becomes plugged, the electrode ceases to function properly).

Flow-Through Cell

In the flow-through cell for continuous O–R potential measurement, the stationary immersion of a pair of electrodes into a medium such as sewage sludge or other industrial waste high in solids concentration, will poison the noble metal electrode, and polarization will occur within a relatively short time. The phenomenon of polarization is not simple to understand or to explain. It may be caused by solution polarization; that is, the potential in the solution may vary from point to point and may be caused by the streaming of electrons to or from the elec-

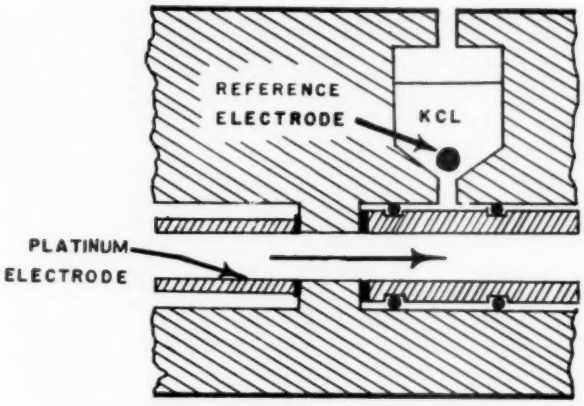

FIGURE 1.—Section through flow cell.

trode, re-orienting charges throughout the medium, or to chemical changes within the medium. On the other hand, electrode polarization may be due to a layer of charges surrounding the electrode, imposing a definite potential barrier.

Many efforts have been devoted to the development of a successfully operating continuous recording O–R potential cell. After considerable developmental investigations, which began in 1948, a workable commercial prototype cell was achieved late in 1955.* The design of this flow-cell is unique in many respects. It represents no obstruction to the flow which prevents the plugging by fibrous materials, as a straight flow-through bore is presented to the larger solids in the sludge. The relatively large area platinum electrode, combined with rapid flow, eliminates solution polarization. Although it is difficult to establish just how effectively this kind of a flow system prevents polarization, due to the lack of a reliable standard potential meter for anaerobic sludge or other waste materials, it appears that an intermediate plateau may be established after some time interval, which recirculation of the media helps to maintain. Whether this potential level is the same type as when initially standardized with quinhydrone solution, remains to be proven. A section through the flow-cell is presented in Figure 1. Figure 2 shows the cell in operation in series with pH and conductivity sensing elements.

The standard half-cell used in the flow-cell is a silver, silver chloride cell: $Ag^{o}/AgCl(S)$, Cl^{-} (sat. KCl); $E_{o} = 197$ mv. The KCl solution serves simultaneously as a salt bridge. This type of half-cell has been described previously (21). A gauge pressure of 2 to 5 psi applied to the KCl reservoir forces the KCl solution to diffuse through a porous porcelain membrane to contact the sludge or other waste material flowing through the tube. Slight overpressure on the KCl reservoir prevents sludge particles from clogging the pores and diffusing upward through the porcelain tube. The liquid junction potential has proven negligible.

The entire assembly is mounted in a teflon block, and electrical connections are made to a commercial potentiometric recorder. The one in use for these studies is a 6-point Foxboro multirecord EMF Dynalog recorder with a range of 0 to 250 mv. All continuous readings of redox potential for the laboratory digesters (Figures 3 through 9) were obtained with these cells.

* Fischer and Porter Co., Hatboro, Pa.

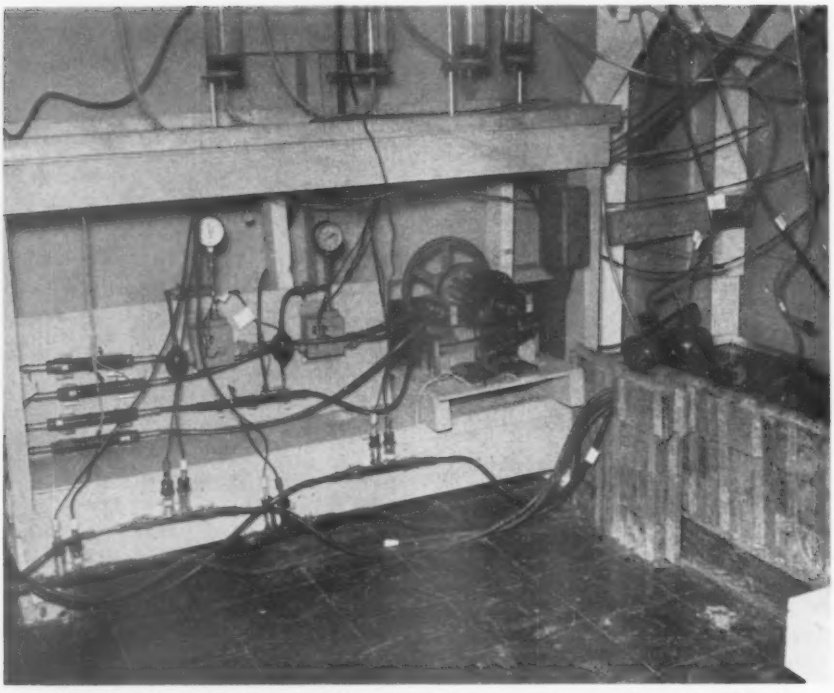

FIGURE 2.—Flow-through O-R potential cells in series operation with pH and conductivity sensing elements.

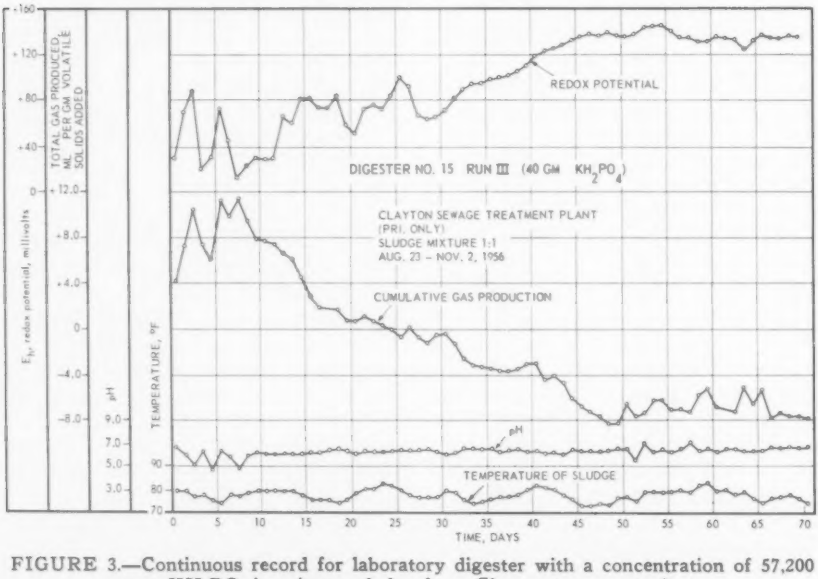

FIGURE 3.—Continuous record for laboratory digester with a concentration of 57,200 ppm KH_2PO_4 in primary sludge from Clayton treatment plant.

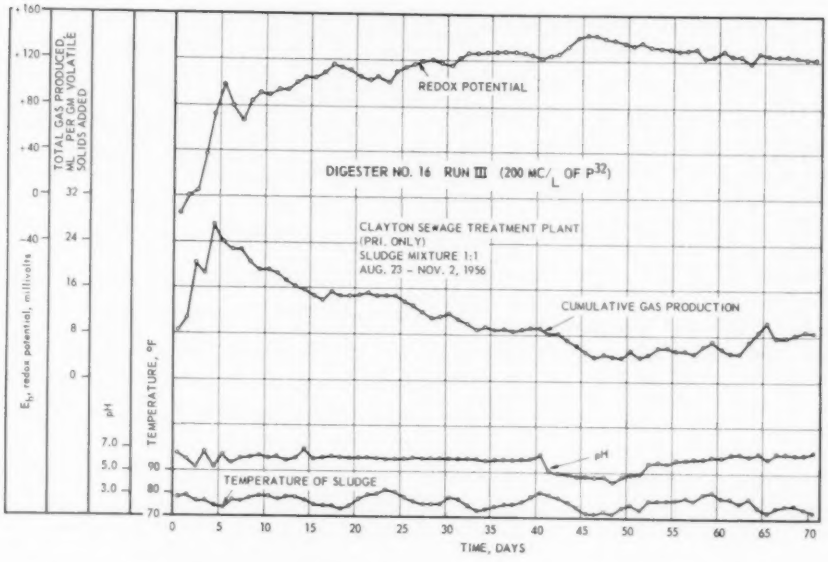

FIGURE 4.—Continuous record for laboratory digester using 200 mc/l of P^{32} with primary sludge from Clayton treatment plant.

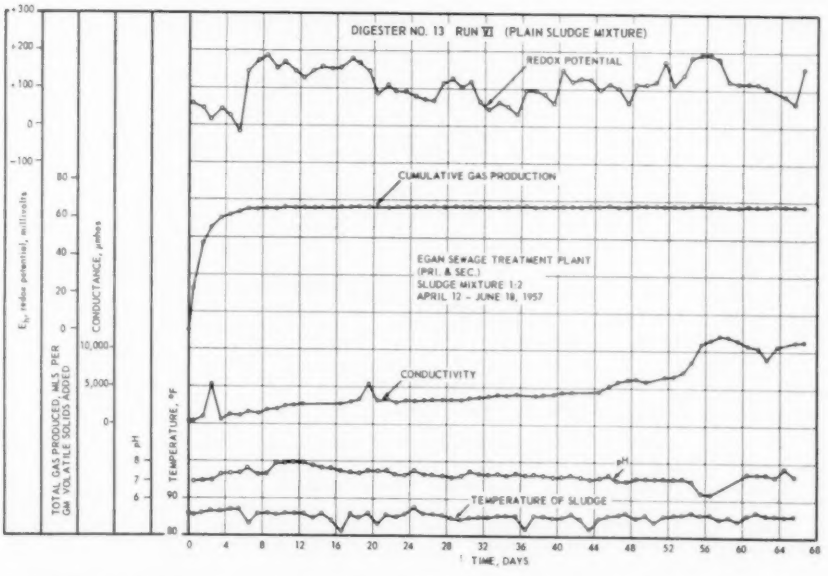

FIGURE 5.—Continuous record for laboratory digester using plain sludge mixture from primary and secondary tanks of Egan treatment plant.

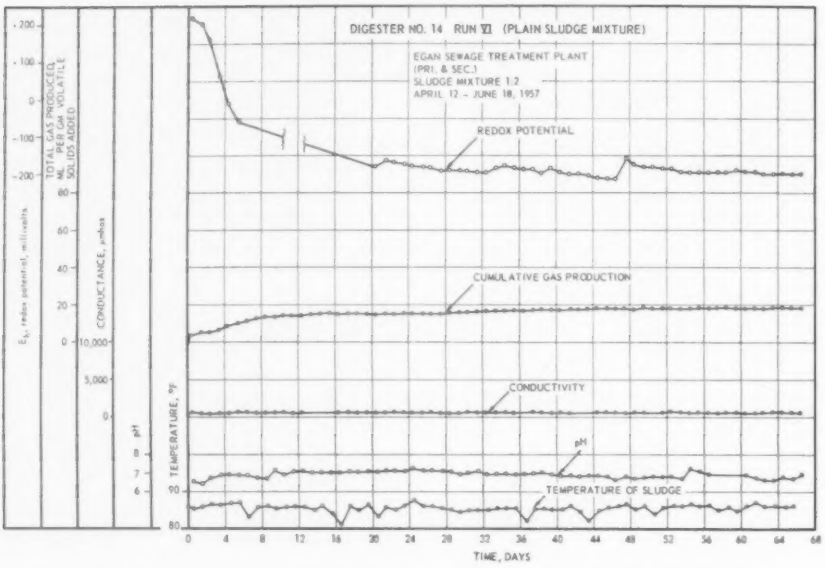

FIGURE 6.—Continuous record for laboratory digester using plain sludge mixture from primary and secondary tanks of Egan treatment plant.

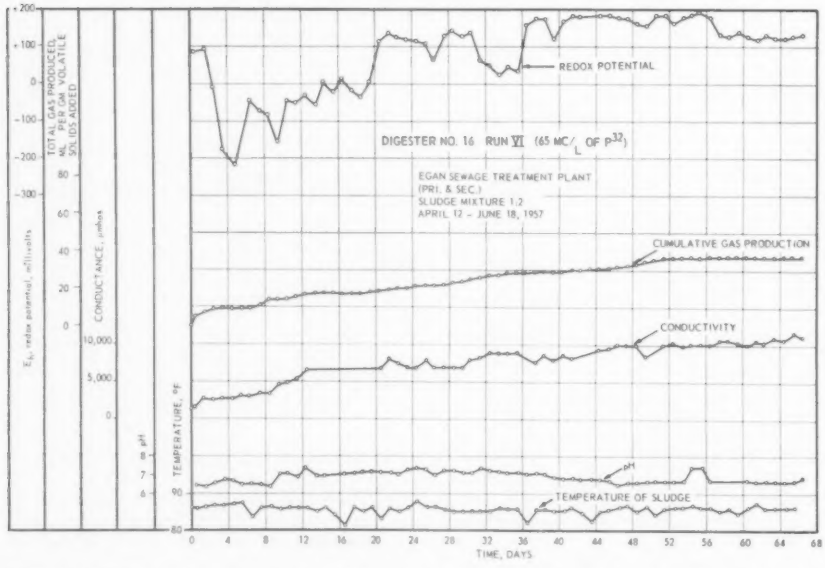

FIGURE 7.—Continuous record for laboratory digester using 65 mc/l of P^{32} with sludge mixture from primary and secondary tanks of Egan treatment plant.

The potentiometer readings obtained by different half-cell systems (that is, calomel and Ag,AgCl) may be referred to a standard potential, E_h (that is, referred to hydrogen half-cell) according to the following:

$$E_h = E_{(cal)} + E_{0(cal)} \quad \ldots\ldots (8)$$

$$E_h = E_{(Ag,\,AgCl)} + E_{0(Ag,\,AgCl)} \quad \ldots (9)$$

with the following notations:

$E_{(cal)}$ = potentiometer reading if the calomel half-cell is used;

$E_{(Ag,\,AgCl)}$ = potentiometer reading if the Ag,AgCl half-cell is used;

$E_{0(cal)}$ = 245 mv at 25° C, the half-cell potential of saturated calomel cell; and

$E_{0(Ag,\,AgCl)}$ = 197 mv at 25° C, the half-cell potential of the Ag,AgCl cell.

Procedures for Determining Redox Potentials

Standardization of Instruments

All the cells and potentiometers used in this work were regularly standardized by quinhydrone buffer solution, prepared from 0.05 M potassium acid phthalate, which has a pH of 4.008 at 25° C, to which a pinch of quinhydrone is added. The O–R potential exhibited by the solution, as measured by a calomel half-cell is 218 mv (22), and is generally accepted as a primary standard in electromotive tension measurements.

In accordance with Eqs. 8 and 9, the potential referred to the hydrogen electrode at 25° C for both types of half-cells should be the same. Accordingly, when the calomel cell is used, the redox potential of the quinhydrone solution at pH 4 is

$$E_h = E_0 + E_{0(cal)}$$
$$= 218 + 245 = 463 \text{ mv}$$

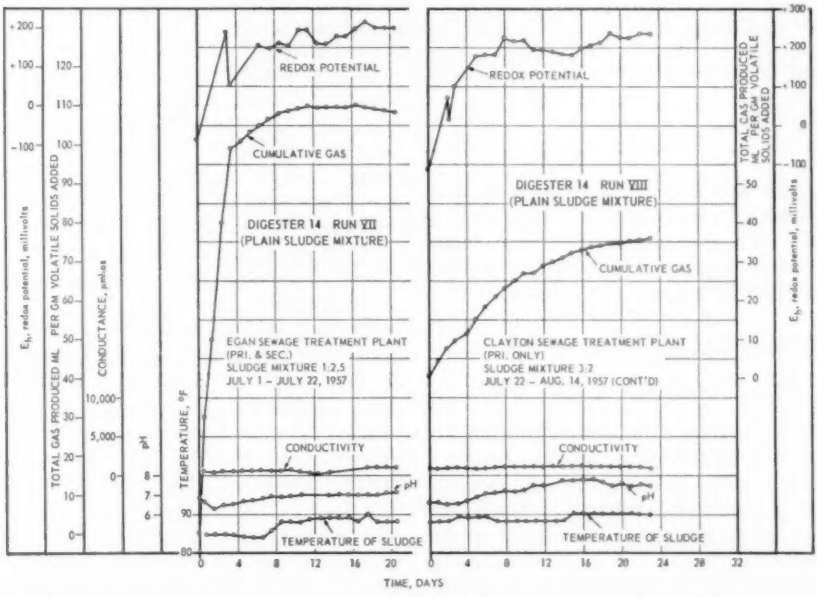

FIGURE 8.—Continuous record for laboratory digesters using plain sludge mixture from primary and secondary tanks of Egan treatment plant and primary tank of Clayton treatment plant.

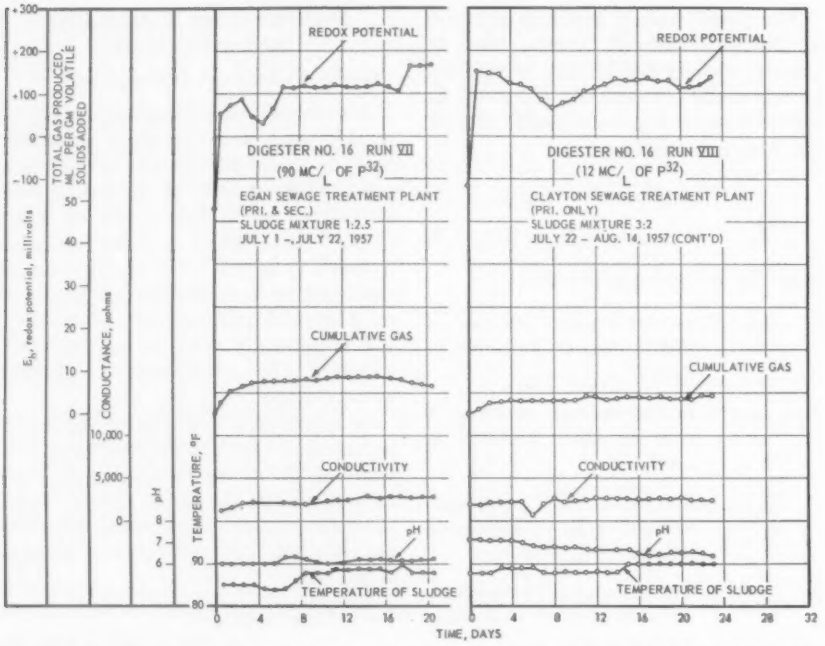

FIGURE 9.—Continuous record for laboratory digesters using 90 mc/l of P^{32} with sludge mixture from primary and secondary tanks of Egan treatment plant and using 12 mc/l of P^{32} with sludge from primary tank of Clayton treatment plant.

and when the Ag,AgCl half-cell is used,

$$E_h = E_{(Ag)} + E_{0(Ag)}$$
$$= 266 + 197 = 463 \text{ mv.}$$

These values of E have been checked on many occasions for all three stationary cells and the flow-cell, and found to lie within ± 2 mv, which is well within the experimental error.

Maintenance of the Electrodes

After the electrodes had been immersed in sludge systems for any period of time, they were thoroughly cleaned before use in another measurement. The importance of a clean, shiny platinum electrode surface cannot be overstressed. Recognizing this factor in the care of electrodes greatly contributed to the success of reproducible measurements.

Various methods for the care and cleaning of electrodes before making potential measurements have been recommended by a number of workers in this field. Nussberger (10) rubbed the platinum electrode in a slurry of Bon Ami to assure exposure of a fresh metal surface; Hood (8) immersed the electrode in nitric acid; and Chang (23) heated the platinum wire in a flame to redness after each potential determination.

From experience herein it was found that washing the platinum electrode in dilute (1.5 per cent) HCl solution, then scrubbing it with a paste of Alconox powder and rinsing it with distilled water until a shiny platinum surface appeared, was generally quite satisfactory. After the commercial flow-cell was exposed continuously to anaerobic sludge for a long period of time, a more concentrated solution of HCl (up to 10 per cent) was necessary and more extensive scrubbing was required.

TABLE I.—E_h Values Obtained for Various Types of Domestic Sludges

Deter. No.	Date (1957)	Source of Sludge[a]	Type of Sludge	Potential, E_h (mv)	Temp. (° C)	Period of Electrode Immersion (minutes)	Remarks
1	5/14	Homemade	Dig.	−66[b]	25	160	
2	5/16	Homemade	Dig.	−145	25	123	
3	5/17	Homemade	Dig.	−223	25	71	
4	5/20	Homemade	Dig.	−150	23.5	133	
5	5/23	Clayton	Raw	−23	24	100	
6	5/30	Homemade	Dig.	−155	25.5	85	
7	5/30	Clayton	Raw	+78	25.5	405	
8	5/31	Homemade	Dig.	−171	25	175	
9	6/5	Clayton	Raw	+85	15	20	Added few drops I_2 (83% alcohol soln)
10	6/5	Homemade	Dig.	−167	21.5	73	Added I_2 } Same sample
11	6/6	Homemade	Dig.	−169	26	290	Added I_2 } Same sample
12	6/6	Homemade	Dig.	−177	26	43	Added I_2 } Same sample
13	7/1	Egan	Raw	−70	24	45	Sludge left standing in beaker
14	7/1	Egan	Prim. Dig.	−130	24	120	
15	7/1	Egan	Mix.	−145	24	70	Mixture of raw and digested
16	7/15	Egan	Mix.	−167	28	160	After 15 days digestion
17	7/23	Egan[c]	Dig. 1	−128	28	68	Digesters 1 to 16 all after 23 days of digestion—see footnote for composition of digester contents.
18	7/23	Egan[c]	Dig. 2	−118	28	11	
19	7/23	Egan[c]	Dig. 3	−121	28	38	
20	7/23	Egan[c]	Dig. 4	+261	28	24	
21	7/23	Egan[c]	Dig. 5	−111	28	113	
22	7/23	Egan[c]	Dig. 6	−119	28	44	
23	7/23	Egan[c]	Dig. 7	−128	28	120	
24	7/23	Egan[c]	Dig. 8	+252	28	123	
25	7/23	Egan[c]	Dig. 9	−99	28	24	
26	7/23	Egan[c]	Dig. 10	−117 −130[d]	28	120 93[d]	
27	7/23	Egan[c]	Dig. 11	−134	28	230	
28	7/23	Egan[c]	Dig. 12	+244	28	120	
29	7/23	Egan[c]	Dig. 13	−136	28	87	
30	7/23	Egan[c]	Dig. 14	−106	28	83	
31	7/23	Egan[c]	Dig. 15	−111	28	33	
32	7/23	Egan[c]	Dig. 16	−99	28	127	

[a] Homemade means usually well-digested sludge; the accumulation of various sludges after use in the laboratory, kept in a 5-gal earthen crock under anaerobic conditions; generally resembles sludge from a secondary digester in character.

[b] Rose to −186 mv after 18-hr additional contact.

[c] Digesters 1 through 3: all plain sludge mixture same as determination No. 15, after 23 days of digestion.

Digesters 4, 8, 12: 4 glucose and seed; 8 glucose, seed, KH_2PO_4 (15.7 gm/l); 12 glucose, seed, radioactive KH_2PO_4 (57.6 mc/l).

Digesters 5 through 7: plain sludge mixture, KH_2PO_4 (15.7 gm/l).

Digesters 9 through 11: plain sludge mixture, radioactive KH_2PO_4 (57.6 mc/l).

Digesters 13 and 14: same as 1 through 3
Digester 15: same as 5 through 7
Digester 16: same as 9 through 11
} Except sludge circulated through pH, O-R potential and conductivity cells.

[d] Added I_2.

Laboratory Results: O-R Potentials for Different Sludges

The redox potentials for the various types and mixtures of sludges obtained from two different sewage treatment plants at Atlanta, Ga., were measured (Table I). The Clayton plant includes primary clarification and two-stage di-

gestion for approximately 65 mgd. The Egan plant, providing complete treatment for 1.5 mgd, also has two-stage digestion but without provision for heating the digesters. During the winter months difficulties with digestion have been experienced. Both plants treat predominately domestic sewage, although the Clayton plant receives some industrial wastes at times.

With a platinum electrode and a calomel half-cell the $E_{(cal)}$ readings on these sludges were found to vary from − 160 to − 500 mv, representing a range of E_h values from + 85 to − 255 mv, as shown in Table I.

It should be noted that although the E_h values for the raw (primary sedimentation) sludge varied from + 85 to − 70 mv, the digested sludge (sludge from primary and secondary digesters) had E_h values ranging from − 130 to − 225 mv.

A distinct difference in the range of E_h values between the raw and the digested sludges on standing is also indicated in Figure 10. The potential for raw sludge appeared to have reached a stabilized point at an E_h value of − 30 mv, whereas that for the digested material was − 150 mv. It is interesting that the potential curve (Figure 10) of a mixture of the two sludges (50 per cent raw and 50 per cent digested) fell between that of the raw and the digested material with a stabilized point at around − 75 mv.

The reason for the sludge mixture potential reaching a stabilized reading sooner may be due to improved temperature control during this test. The temperature variation during the period of measurement as otherwise stated in Figure 10 was relatively insignificant. The total temperature increase was 2.9° C during raw sludge and digested sludge measurements, with 0° C variation for the mixture. The implication of temperature effect will be discussed later. The same general potential trend from + 50 mv to 0 mv in E_h value during a 100-min period is also shown in Figure 11. It may be stated from these various observations that a range of E_h value from 0 to + 50 mv may be expected for this type of raw domestic sludge.

The high positive potentials obtained in the seeded glucose experiments are

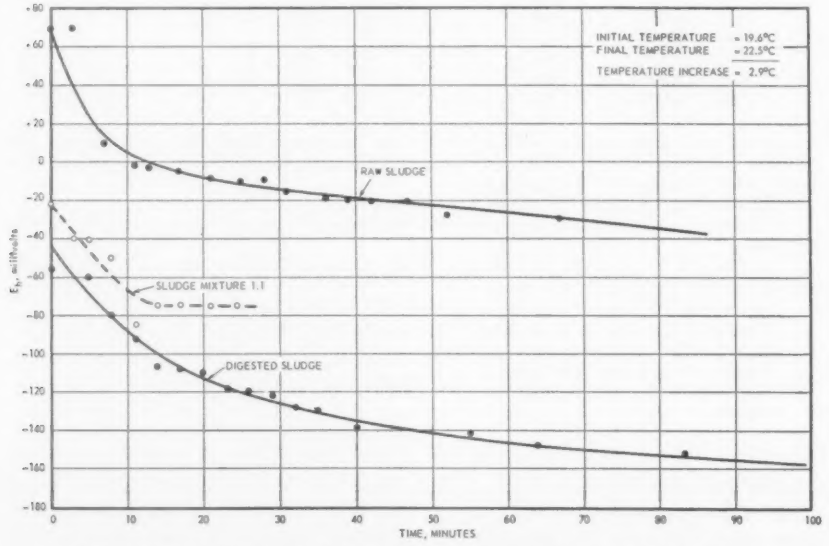

FIGURE 10.—Time-potential curves for raw, mixed, and digested sludge.

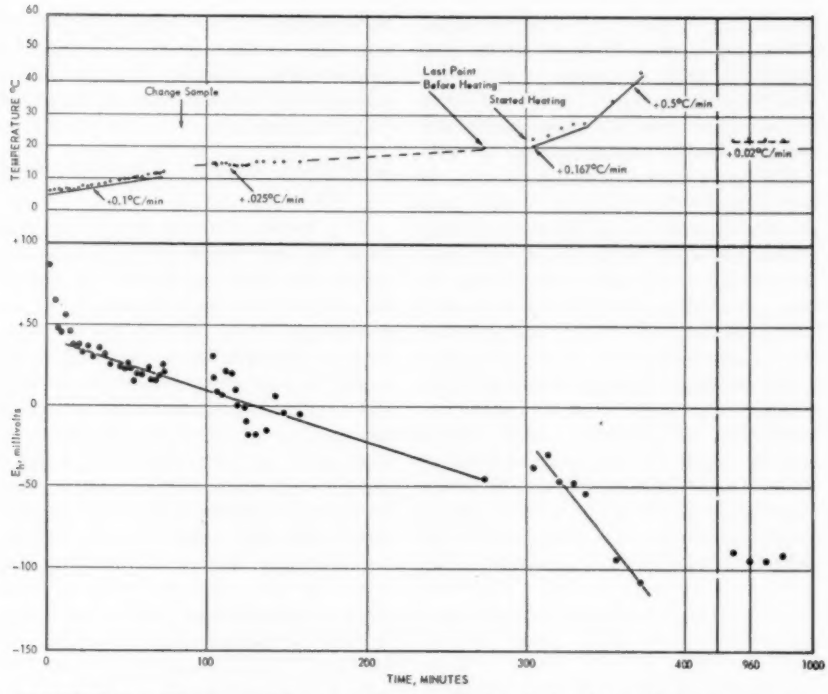

FIGURE 11.—Time-potential curves for raw sludge during increasing temperatures.

of further interest (Table I, determination Nos. 20, 24, 28). It is apparent that active anaerobic decomposition was never established in those digesters during the 23-day period of experimentation, as reflected by poor gas production (composition of the gas, 95 per cent CO_2), pH (in the range of 4.0), and percentage volatile matter destroyed. The potential values for digesters 4, 8, and 12 are + 261, + 252, and + 244 mv, respectively. The reason for this high potential may indicate the presence of facultative microorganisms, which thrived on and assimilated molecular oxygen available from the high sugar concentration. At the end of 23 days of experimentation these digesters were seeded again. A few days after reseeding, anaerobiosis was finally established and the potentials became definitely negative. This demonstration of O–R potential to determine the status of the digestion process, or the stage of digestion, shows its value as a true indicator of fermentation conditions.

Laboratory Results: Time Requirement

Measurement of O-R potentials in biological systems is not instantaneous as with pH for reasons stated earlier. One apparent feature encountered in measuring the O–R potentials of sludges, industrial wastes, and even bacterial cultures, is the time required to obtain a stabilized reading. Although sometimes 2 hr or more may be required before a stabilized reading is reached, preliminary observations showed that 80 to 90 per cent of the final stabilized value potential was reached within 30 min after immersion of the electrodes into the sludge.

Two typical time-potential curves from carefully taken data were plotted (Figure 12). The reproducibility of the change of redox potential against time should be noted in Curve I. These

results were obtained on different days, although the same kinds of sludge and electrodes were employed. The same time-potential trend is shown in Curve II, obtained with the short electrodes of the Model G potentiometer.

For pure chemical substances it is not difficult to distinguish the true reading, because equilibrium is quickly established and the potential measurement is almost instantaneous. This has been referred to as a static system (9). The period necessary for stabilization in a dynamic system, such as in the decomposition of sewage and industrial sludges, was recognized by other investigators (8)(9)(20). Although a certain length of time is required to achieve an equilibrium state between electrodes and the system to be measured, it is still too early to state definitely whether this prolonged period required for a "stabilized" reading may not be mistaken for time for polarization. Possibly the truth lies somewhere between the initial and final readings.

Laboratory Results: Potential Mediator

It is known that for some O–R Systems it is almost impossible to obtain accurate potentials because of uncertainty as to the exact concentrations of the substances involved or the slowness with which equilibrium with the inert metal of the electrode is established (24). It is probable that whenever the number of electrons, the value of n, involved in the O–R system is large, the O–R processes occur in stages, one or more of which may be slow (13) (14). In that event equilibrium between the system and the electrode will

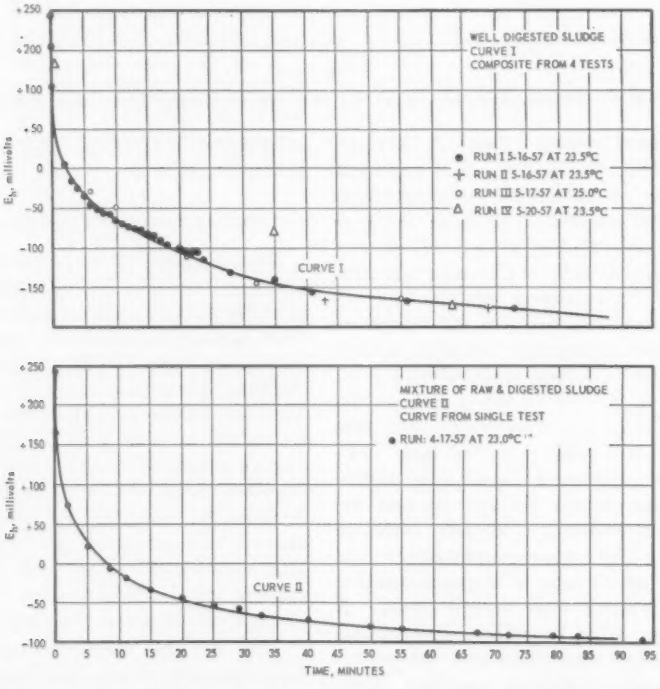

FIGURE 12.—Typical time-potential curve during warm-up period as indicated on model WM 500 redox amplifier (Curve I) and Model G potentiometer (Curve II). Curve I shows 80 per cent or more; Curve II, 85 per cent or more of the potential reached in 25 min.

be established slowly and the measured potential may be in error. The role played by a potential mediator is to expedite the attainment of equilibrium conditions during potential measurement. It is a substance which undergoes reversible oxidation-reduction and rapidly reaches equilibrium with the electrode.

Iodine was used as the potential mediator. The platinum electrode measures the potential of the iodine-iodide ion system, which in turn should be equal to the potential of the unknown sample because it is in equilibrium with the mediator system. In a few of the experiments shown in Table I small amounts of iodine (I_2 in 83 per cent alcohol solution) were added to the sludge samples. As shown by the results obtained, in some cases the addition of iodine distinctly reduced the equilibrium and the time required for measurement to less than 30 min, whereas in some cases no apparent effect was shown. The complete role played by the mediator to bring about this sharpened potential is not yet fully understood and additional work is necessary.

Laboratory Results: Determination of Layering Effect

To determine if any real difference exists in potentials at various levels of a digester during the anaerobic process, one of the experimental digesters was opened during a laboratory run and O–R potential values at different depths were measured directly with the use of the Beckman H–2 potentiometer. It was noted that the readings varied with the position of the electrodes in the bottle digester. After 17 days of digestion, the upper part of the digester consisted of liquid supernatant and the E_h value was + 145 mv; that of the bottom half, containing the digesting solids, was − 105 mv. After thorough mixing, the E_h value of the mixed content was found to be around − 25 mv.

In another experiment, using digested sludge taken from a 5-gal laboratory crock, a sample was kept in an open beaker for two days. A layer of white mold formed on the surface. The sludge solids, buoyed up by the gases of decomposition, floated just below this moldy growth leaving a rather clear fluid near the bottom. When the potential of the content was measured with a Beckman WM–500 meter, three different O–R potential readings were obtained—an E_h value of − 15 mv in the moldy layer, a value of − 135 mv in the gas-lifted solids, and + 355 mv in the bottom liquid portion.

Therefore, in referring to potentials in a digester, it is necessary to indicate from which layer of the digested material it is obtained, since definite layering may be observed which can be characterized by O–R potential. When reporting redox potentials for anaerobic treatment one must distinguish between zones of active digestion, scum and grease layer, and supernatant.

In the present study, unless otherwise stated, it was the solids portion of the digester that was measured and reported. This was the part which underwent anaerobiosis. Higher values of potential for the supernatant have been reported by others (8)(9).

The E_h value of + 355 mv obtained with the supernatant in the second experiment could easily be explained by the fact that it picked up oxygen when the sample was poured into the beaker.

In the prototype treatment plant digester it would therefore be desirable to install several flow-cells to overcome the layering effect, especially for digesters that employ no mechanical mixing of the sludge.

Laboratory Results: Temperature Effects

Temperature has a distinct influence on O–R potentials of waste treatment systems. Its effect is quantitatively shown in Eq. 1*a*. Furthermore, according to the Van't Hoff Arrhenius law, a definite temperature dependence

exists on the rate of digestion in biologically active, anaerobic digestion. However, in measuring the potentials it often is inadequate to know only the temperature under which a particular experiment was performed, but the antecedent conditions to which the system was exposed also should be analyzed carefully. Thus, whether raw sludge was previously exposed to heat or cold, temperatures will affect the measurement potential. When a sample of raw sludge is removed from a sedimentation tank hopper and placed in a laboratory refrigerator, the bacterial metabolism is bound to be greatly reduced.

Most bacterial cultures are reducing systems, due to the metabolism of the organisms. Consequently, free oxygen will be quickly exhausted from the system and negative potentials become rapidly established Other systems in which reducing conditions occur are the wastes containing metabolic products of bacterial activities. Thus, the rate at which reducing conditions become established will usually be indicative of the degree of biological activity. Rapid establishment will be a sign of a high degree of bacterial metabolism; conversely, a very slow change in potential will indicate a lower degree of biological activity. With mesophilic and thermophilic bacteria, the higher the temperature the more rapid is their reducing system established.

Several experiments were performed to investigate how the temperature affects the bacterial decomposition activities as reflected by the O–R potential changes. A 2-gal sample of raw primary sludge was collected from the Clayton sewage treatment plant and quickly brought to the laboratory. It was placed in the refrigerator and held at 5°C for 16 days to slow down or inhibit further breakdown of organic matter. A portion of the raw sludge sample was then brought into the laboratory (room temperature, 24°C) and subjected to a potential analysis.

During the initial warm-up period readings were taken every 2 or 3 min for 1½ hr. Figure 11 shows that the E_h value dropped from + 85 mv to + 20 mv during the first 75 min while the temperature of the system increased at the rate of 0.1°C per minute. After 100 min, another sample of raw sludge, which was removed from the refrigerator at the same time as the first sample and treated identically up to this point, was substituted to assure the reproducibility of the potential. This is indicated as "Change Sample" in Figure 11.

The experiment was resumed and the same electrodes and meter were used. Still remaining as the only variables were temperature and reactivity of the system. The O–R potential continued to fall, because bacterial activity and anaerobiosis were enhanced at 15°C. The temperature gradient decreased to 0.025°C per minute; after an additional 3 hr, the temperature had reached only 20°C. During this interval, the E_h value dropped from + 20 mv to − 45 mv, which could be explained by the increased bacteriological activity and the activation of enzymes at the onset of reducing conditions resulting from the heat energy supplied to the system.

After 300 min a more rapid temperature rise was brought about by artificial heating of the sludge sample. The time-potential curve assumed a more negative slope within 20 min. As the temperature gradient of the system swiftly increased to 0.5°C per minute, an E_h value of − 115 mv was reached in 1 hr, when the temperature had risen to 43°C.

The next morning, 960 min after the start of the experiment, the potential was still at about the same value, which would be expected with a very poorly seeded raw sludge sample, and the temperature had dropped off to room temperature. It may be concluded that as soon as the heat energy, acting as a catalyst for the biological reactions, was removed, the system reverted to the relatively low degree of

biological activity it had previously held.

Because the reactions underlying anaerobic digestion are largely biochemical in nature, the temperature effect on the O–R potential must be attributed to the increased growth activities of the bacteria. Hence, the rapidity with which the O–R potential dropped as the digestion temperature was increased confirms the extent of bacterial respiration at work in sludge digestion.

Further experiments are indicated for a quantitative interpretation of the temperature effect on O–R potentials in anaerobic systems. Well-seeded identical mixtures should be incubated at definite temperatures for periods up to 90 days. The temperatures should be the same as those employed by Fair and Moore (25), for which they established the relative times for digestion. This relative time necessary for digestion would serve as a criterion for the potentials to be obtained. A family of time-potential curves for the various temperatures can be expected, which would yield valuable information.

Laboratory Results: Flow-Cell O–R Potential

The results of four laboratory runs, part of a study of the effect of radioactivity on sludge digestion, are shown in Figures 3 through 9. These results represent only those from digesters equipped with redox potential flow-cells for continuous measurement. In each of the laboratory runs, those digesters fed with radioactivity are clearly indicated in the figures.

All continuous O–R potential data as shown in these figures were obtained with the Fischer and Porter flow-cells. In all cases where active gasification occurred, the redox potential curves showed some rapid changes during the period. This is in full accord with prestated assumptions, as well as the previous observations. These curves are also quite similar to those presented by Vennesland and Hanke (26) in their work with *Bacteroides vulgatus* cultures under anaerobic conditions maintained by regulating the atmosphere above the cultures. One of their potential graphs is reproduced in Figure 13, in which the close resemblance in potential drop to that observed here is of considerable interest. The onset of acidification (with a pronounced turbidity increase), similar to active decomposition and gasification during sludge digestion, should be noted.

It must be pointed out that in order to prevent plugging of the small laboratory flow lines (⅜-in. ID) all sludges were screened. This altered the content of the sludge because the large particles were removed in the screening process. This may be the explanation for the relatively low gas production yields.

Many of the large sludge particles removed by screening normally contain a large proportion of the most resistant compounds, including the lignins, celluloses, rubber, and sulfur-containing compounds. This might provide the explanation of why the O–R potentials did not reach as low, negative values as ordinarily expected. For the main purpose of these experiments, the effects of radioactive wastes on anaerobiosis, comparison of the average reaction velocity constant, k, and ultimate gas production, L, parameters is still valid to obtain the significance of the radioactive effects.

In Figures 3 through 9 it is shown that as the potential moves to higher and higher positive values, the digestion is more and more complete. It appears that a value of E_h of + 100 mv indicates that most of the decomposable organic matter is stabilized in the digesting medium. On the other hand, there were relatively rapid changes in E_h values in the range of 0 and − 150 to − 200 mv during the first few days in well-seeded, actively fermenting digesters. Therefore the O–R potentials indicate, along with the other parameters, the activity of the sludge and its aptitude for digestion.

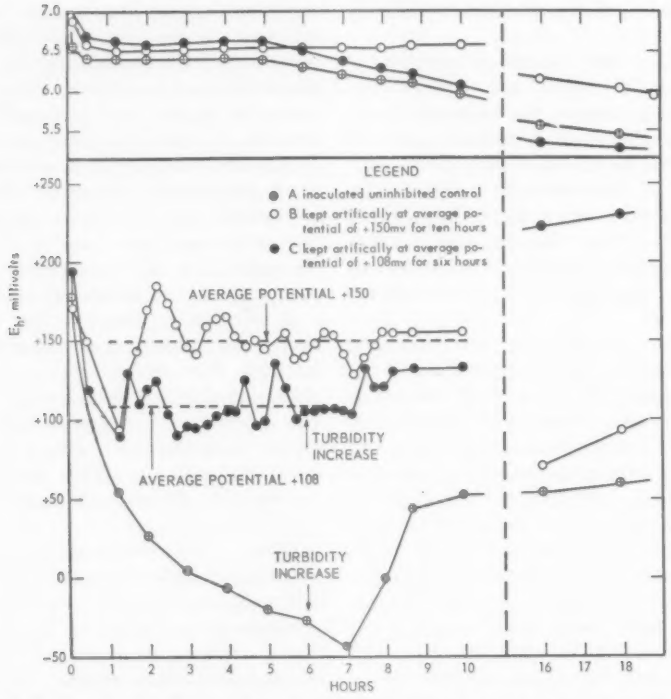

FIGURE 13.—pH and potentials of *Bacteroides vulgatus* cultures kept at controlled potential levels by a nitrogen-air gas mixture (after Vennesland and Hanke (26)).

It also appears to illustrate the toxic effect of radioactivity. When gas production is inhibited, the potential shows little or no further change.

Summary and Conclusions

Much of the present theory and explanations for redox potentials in waste treatment practice are still not fully understood or established. When working in this field great care must be maintained to prevent speculation too far with the present knowledge.

The few conclusions which can be drawn about redox potentials in anaerobic waste treatment may be summarized as follows:

1. The time to establish a stabilized potential may be as long as 2 hr. This may be due to the step-wise oxidation-reduction phenomena accompanying complex heterogeneous systems such as those reported herein, where a number of electrons are involved and one of the governing reactions is very slow to proceed.

2. In addition to pH, which should always be reported along with O–R potential values, the potentials are a definite function of temperature, which agrees with the theory. Additional work is necessary to define more clearly this temperature dependence on redox potential in anaerobic digestion.

3. The variation of O–R potential with different layers in a digester can be clearly demonstrated and it is possible that this tool will first be used to characterize the layering in prototype digesters. It is recommended that several O–R potential cells be employed in prototype installations.

4. Raw sludge appears to have a potential of + 85 to − 20 mv and a rather rapid rate of change under the

proper seeding and temperature conditions.

5. Well-digested sludge appears to have a potential of − 250 mv and the rate of change is slow because biological activity is nearing its end.

6. A well-digesting, truly anaerobic mixture of domestic sludge appears to be operative in a range of − 100 to − 250 mv.

7. From the continuous redox potential curves obtained with the flow-cells, the potentials are higher than those previously mentioned because the sludge is screened and therefore different from that in the plant. Further work to analyze and correlate these potentials is required.

In conclusion it may be stated that redox potential alone can never be expected to describe completely the status of a waste or a process. It can, however, in certain areas shed that often needed additional information, as in times of operational troubles, towards a more complete analysis of the underlying processes. It is capable of yielding information of a type and nature which no other parameter available to the sanitary engineer is able to provide. When better understood it is certain that O–R potential will take its place among the many other time-proven criteria available to the profession.

Acknowledgments

Appreciation is extended for the assistance of a number of colleagues and assistants who have been associated with various phases of this research project: Robert H. Philp, Donald E. Saire, and James V. Carter, Jr. Much assistance was given by Thomas H. Lotze and Robert L. Rice of the Fischer and Porter Company and to Messrs. Bishop and Kehoe of Beckman Instruments, Inc., as well as Russel H. Babcock of the Foxboro Company, who made many of the necessary instruments available and provided technical service in connection with these investigations.

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DISCUSSION

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The authors have reviewed O–R potential theory and have presented a new avenue of application in sludge digestion. Unfortunately, specific application of O–R potential to many waste treatment problems is limited by the complex nature of the systems involved. Professor Grune has indicated that the relationship between E_h and pH cannot be established in the complex systems usually encountered in sewage and waste treatment. For example, in a tomato waste the potential decreased 48 mv per unit increase in pH, while in a sulfide waste studied a decrease of only 12 mv per unit pH increase was found. In all systems observed in these studies an increase in pH resulted in a decrease in potential. It readily can be seen that in wastes where automatic control is to be employed pH control is a mandatory adjunct to O–R potential control.

The authors have discussed the application of O–R potential to the interpretation and control of anaerobic digestion systems in laboratory and plant operation.

A few other examples in chemical and biological waste treatment may be cited to illustrate O–R potential application.

Recently, experiments were conducted employing O–R potential to control the aeration or chlorination of a waste water containing sulfides, sulfites, and thiosulfates (Figure 1). In this waste, sulfide is the most reduced form with a

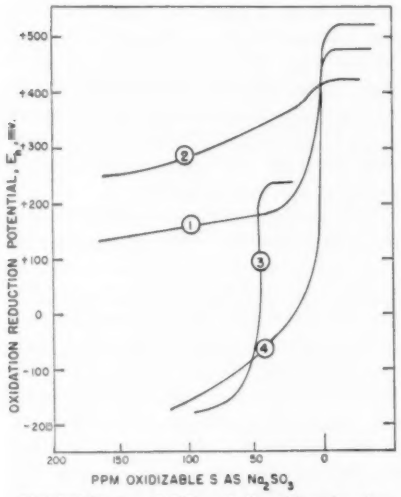

FIGURE 1.—ORP relationships in the oxidation of sulfur compounds.

valence of − 2; sulfate is the most oxidized form, with a valance of + 6. Thiosulfate and sulfite are intermediate forms with valences of + 2 and + 4, respectively. Aeration will oxidize sulfite to sulfate and will remove sulfide as hydrogen sulfide by stripping, depending on the pH of the system. Chlorination will result in oxidation of all the reduced sulfur forms. In aeration of a pure solution of sulfide and sulfite at pH 2.7 an abrupt change in potential occurs when the sulfide is substantially stripped from solution. A similar pattern is developed from the oxidation of sulfite.

Aeration of the mixed waste results in oxidation or removal of only a portion of the waste constituents. The potential rises to an equilibrium value following this oxidation.

Chlorination produces a sharp break in the curve when all the sulfur compounds are oxidized. This type of process is readily adaptable to automatic control, since as the end point of the process is approached a small increment addition of oxidant produces a large change in potential. A similar curve may be developed from the chlorination of cyanides.

Biological systems exhibit a dynamic characteristic in that the potential changes with time due to alteration of the oxidant-reductant ratio. In aerobic systems, such as the activated sludge process, it may be postulated that the O–R potential is related to the dissolved oxygen content and to the organic matter which is readily reduced when the available oxygen is consumed by the culture. It should be noted that

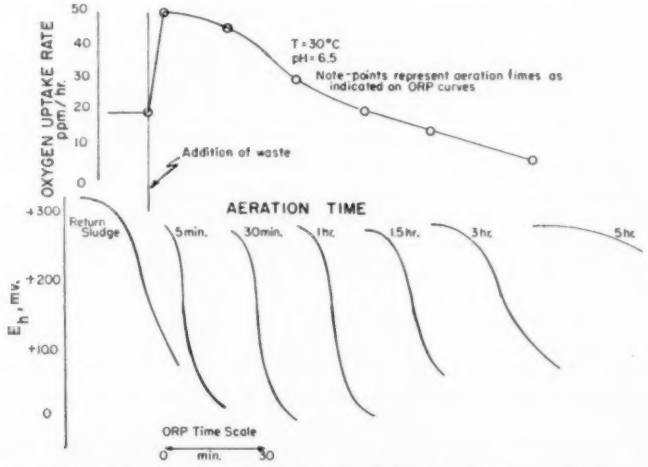

FIGURE 2.—ORP relationships in the bio-oxidation of pulp and paper mill wastes.

organic matter *per se* will have little influence on the potential and it is the enzymatic activity of the system acting on available organic matter which will establish strong reducing conditions. It is obvious that both the rate of change of potential and the ultimate potential reached are significant.

The laboratory measurement of O–R potential on biological sludge systems involves special considerations. A technique has been developed in which the sludge mixture is maintained in suspension in a sealed flask and the O–R potential change noted with time.

In typical data from an activated sludge plant treating pulp and paper mill wastes it was observed that the slope of the potential-time curve decreased with time of aeration and with decreasing oxygen utilization rate as the available organic matter was stabilized by oxidation (Figure 2). It has been noted that the initial inflection point in the potential-time curve is that point at which all the available dissolved oxygen has been consumed.

In this system the uptake rate fell to less than 2 ppm per hour and there was substantially no change in the potential over 50 min after 29 hr aeration. This laboratory procedure should prove useful in activated sludge plant control, particularly where more elaborate methods of sludge activity measurement are not available.

The authors have discussed the flow-through cell for continuous measurement of O–R potential and noted its application to sludge digestion. A similar flow-through cell was employed to control an activated sludge pilot plant at Ridgewood, N. J., where the redox potential was employed to modulate the air flow to the process. The O–R potential is shown to be not directly related to the dissolved oxygen content, but rather to the ratio of over-all oxidant to reductant. This has been observed to result in a floating control point in which higher dissolved oxygen levels were observed at those times when the organic loading to the process was greatest. Cleaning of the cell was required only at several weeks' intervals.

VI AIDIS CONGRESS

The VI Congress of the Inter-American Association of Sanitary Engineering will be held in San Juan, Puerto Rico, May 18–24, 1958.

A program has been arranged to take full advantage of the locale for inspection trips, as well as the opportunity for technical presentations. Technical papers will be given during morning sessions and inspection trips conducted during the afternoons. Exhibitions by manufacturers will include equipment, machinery, and materials. There will also be non-commercial exhibitions by governmental agencies.

The time allocation for technical papers is 40 per cent on water works and sewage, 40 per cent on public health, and 20 per cent on general technical or administrative subjects related to sanitary engineering and public health.

Hotel reservations are made through Mr. C. M. Ferguson, Southerland Tours, P. O. Box 4606, Tetuan Street, San Juan, Puerto Rico. Package rates including eight nights in a hotel are available from $48.50 to $111.00 for single and from $44.50 to $79.50 per person for double rooms.

For any other information or clarification, contact Mr. Enrique Ortega, General Secretary, P. O. Box 218, San Juan, Puerto Rico.

OXYGEN DEMAND MEASUREMENT ERRORS IN PURE ORGANIC COMPOUNDS—NITRIFICATION STUDIES *

By P. E. Gaffney and H. Heukelekian

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Oxidation of ammonia nitrogen to nitrite or nitrate is a source of serious error in certain BOD measurements. In the usual 5-day BOD test on sewage, industrial wastes, or pure organic compounds, nitrification does not occur, due to the relatively few numbers of nitrifying organisms in the sewage and their slow rate of multiplication. Nitrification under these circumstances does not usually begin until after the seventh day of incubation; the oxygen demand of the ammonia-nitrogen is excluded, therefore, from the 5-day BOD value.

It has been demonstrated (1)(2), however, that nitrification causes serious error in BOD measurements on secondary effluents from sewage treatment plants. These effluents are in an active state of nitrification when obtained and the 5-day BOD value may include so much nitrogenous BOD that negative BOD removals may be indicated for the treatment process, even though only a small amount of carbonaceous material remains. Sawyer (1) has proposed a method of eliminating the nitrifying organisms from these effluents. He has shown that either flash pasteurization, acidification, or chlorination of the effluent completely kills the nitrifiers, or at least inhibits their activity for 5 days. The dilution water used in the 5-day test was seeded with fresh sewage and he obtained reliable 5-day carbonaceous BOD values.

The necessity for the study reported here became evident during intensive oxygen demand measurements of fatty acids and other pure organic compounds. In determining the cumulative oxygen demand of high concentrations of fatty acids (10,000 ppm) long lag periods were often encountered (3), which necessitated long incubation periods with consequent nitrification. The same problem was encountered when it was desired to measure the 20-day BOD, even when an initial lag period was not observed. This report, therefore, deals with the methods employed in attempting to eliminate errors in observed BOD due to oxidation of NH_3-N during the 20-day measurement period.

Nitrogen Concentration in Dilution Water

Only that amount of ammonia will be oxidized which is in excess of that required for the growth of the heterotrophic organisms that oxidize the carbonaceous material. For the synthesis of protoplasm ammonia is assimilated directly without oxidation.

Butterfield (4) has shown that numbers of bacteria and amount of cell protoplasm accumulated are related directly to the food concentration. Therefore, the amount of nitrogen assimilated for cellular growth would also be directly related to the food concentration (BOD).

An attempt was made to determine the proper BOD:N ratio to use in order to leave no excess NH_3-N available for oxidation by the autotrophs.

* Paper of the Journal Series, New Jersey Agricultural Experiment Station, Rutgers University.

TABLE I.—Influence of Nitrogen and Phosphorus Concentration on the 5-Day BOD of Different Concentrations of Acetate

Acetate Conc. (ppm)	Standard Dilution Water				Modified Dilution Water			
	NH_3-N (ppm)	PO_4-P (ppm)	5-Day BOD (pts/pt)	BOD:N:P Ratio*	NH_3-N (ppm)	PO_4-P (ppm)	5-Day BOD (pts/pt)	BOD: N:P Ratio*
2.0	0.55	12.1	0.75	100:40:800	—	—	—	—
8.0	0.55	12.1	0.77	100:10:200	—	—	—	—
100†	0.55	12.1	0.56	100:0.6:12	4.0	0.8	0.76	100:5:1
1,000†	0.55	12.1	0.09	100:0.06:1	40	8.0	0.75	100:5:1

* Based on an expected BOD of approximately 0.8 part of O_2 per part of acetate.
† Warburg method.

For this purpose, the oxygen demand of various concentrations of acetic acid was determined with standard dilution water and with a modified dilution water, the nitrogen and phosphorus content of which was increased with increased acetate concentrations to give a BOD : N : P ratio of 100 : 5 : 1. Seeding was made with 0.1 per cent sewage in all cases. The pH values were adjusted to 7.0 with the high concentrations of acetic acid used. The results of this study are presented in Table I. It has been shown elsewhere (3) that under favorable conditions of oxidation the 5-day oxygen demand is 0.7 to 0.8 part of oxygen per part of acetate; thus, any value lower than this indicates an unfavorable factor. It will be seen that values of 0.7 to 0.8 were obtained with 2 and 8 ppm acetate in standard dilution water, but not with 100 and 1,000 ppm acetate with BOD : N : P ratios of 100 : 0.6 : 12

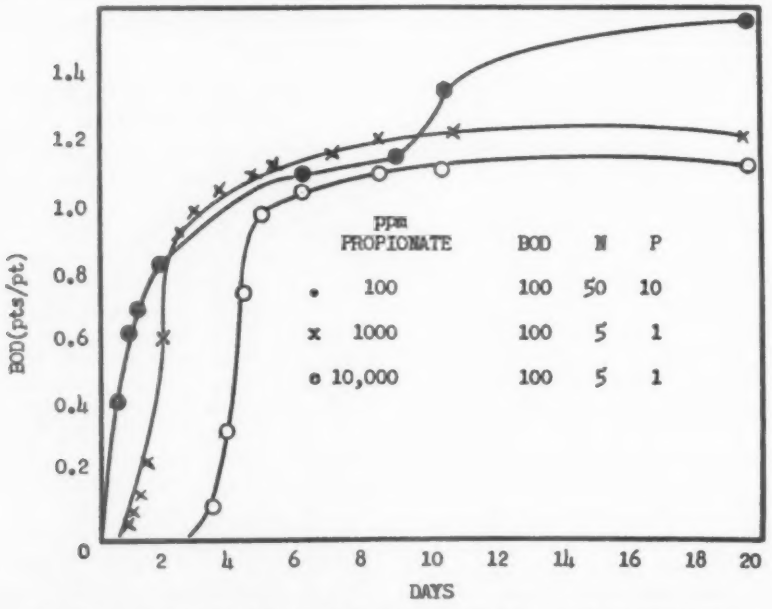

FIGURE 1.—Effect of BOD:N:P ratio on oxygen demand of propionate.

and 100:0.06:1. From these results the low oxygen demand values for 100 and 1,000 ppm acetate are due apparently to a nitrogen rather than a phosphorus deficiency. This is confirmed by the results obtained with the modification of standard dilution water. BOD values corresponding to those at lower acetate concentrations were obtained when the BOD:N:P ratio of 100:5:1 was maintained.

By maintaining this BOD:N:P ratio nitrification does not occur, as manifested by a lack of inflection in the curves up to 20-days incubation (Figure 1). These graphs are the result of an experiment in which the oxygen demand of 100, 1,000, and 10,000 ppm propionate was measured for 20 days using the Warburg respirometer. The BOD:N:P ratio of 100:5:1 was maintained in the 1,000- and 10,000-ppm samples and no nitrification occurred. With 100 ppm propionate, however, the ratio was increased to 100:50:10 and nitrification began on the ninth day, as indicated by the inflection in this curve.

From these results, it appears that a BOD:N ratio of 100:5 is barely sufficient to support the maximum amount of carbonaceous oxidation, leaving no excess NH_3-N available for nitrification.

Where a lag period is observed with a compound, making it necessary to measure the cumulative oxygen demand beyond 5 days, or where the measurement of a 20-day BOD value is desired, the oxidation of an excess NH_3-N would become a serious source of error in the oxygen-uptake measurement.

It has been shown (Figure 1) that this error could be eliminated by supplying only the amount of nitrogen required to support the expected carbonaceous BOD. However, it is not usually possible to know the expected BOD in advance; therefore, it was necessary to find a better and more practical method of preventing nitrification.

Pasteurization

It has been demonstrated that pasteurization, chlorination, or acidification (1)(2) can effectively eliminate the errors created by nitrification during the 5-day BOD determination of secondary effluents. In these modifications, the dilution water is seeded with settled sewage. It is not likely that the nitrifying organisms introduced in the relatively small amount of seed can

TABLE II.—Changes in NO_2- and NO_3-N Content in the Oxidation of Carboxymethylcellulose with Seed Pasturization and Different Nitrogen Sources

Seed	Source of N	Days	ΔNO_2-N* (ppm)	ΔNO_3-N* (ppm)	NOD† (ppm)
Unpasteurized	NH_3	0	0	0	0
Unpasteurized	NH_3	5	0	0	0
Unpasteurized	NH_3	6.0	0.03	0	0.1
Unpasteurized	NH_3	7.0	0.06	0	0.2
Unpasteurized	NH_3	7.8	0.12	0	0.4
Unpasteurized	NH_3	8.8	0.12	0	0.4
Unpasteurized	NH_3	10.0	0.18	0.20	1.5
Unpasteurized	NH_3	13.0	0.17	0.41	2.5
Unpasteurized	NO_3	0	0	0	0
Unpasteurized	NO_3	13	0	0	0
Pasteurized	NH_3	0	0	0	0
Pasteurized	NH_3	13	0.01	0	0

* Increase in NO_2- or NO_3-N content.

† (NO_2-N × 3.43) + (NO_3-N × 4.57) = ppm NOD (nitrogenous O_2 demand).

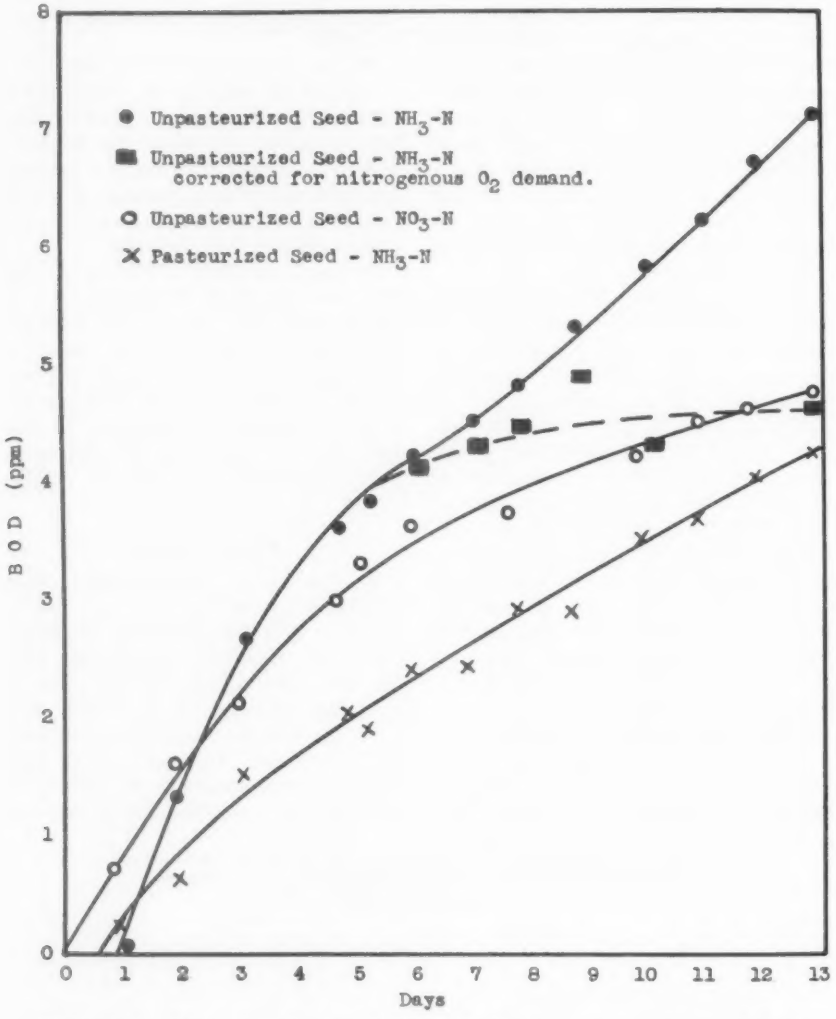

FIGURE 2.—Effect of seed pasteurization and nitrogen source on oxygen demand of 20 ppm CMC.

initiate nitrification during the 5-day incubation period once the massive number of nitrifying organisms in the substrate are inhibited by the treatment of the nitrified effluent. There is a likelihood, however, that the nitrifying organisms in the seed (settled sewage) could multiply and utilize oxygen in the oxidation of ammonia to nitrite and nitrate over incubation periods longer than 5 days. That such is the case is shown by the results in Table II.

The substrate studied was carboxymethylcellulose (CMC) using the jug method (5). When this was seeded with settled sewage and furnished with NH_3-N, nitrification started after 5 days. When the seed was pasteurized

(heated to 60° C and cooled immediately to 20° C) nitrification did not take place. Figure 2 presents the oxidation of CMC when furnished with ammonia and seeded with pasteurized and unpasteurized sewage, also CMC furnished with NO_3-N and seeded with unpasteurized sewage. The BOD kept increasing up to 13 days with NH_3-N and unpasteurized seed, which when corrected for the oxygen demand of the NO_2 and NO_3 produced showed a flattening of the curve after 6 days, and close agreement with the BOD values obtained in 13 days when NO_3-N was used in place of NH_3-N. That pasteurized seed gave lower BOD values than any of the others during the entire 13-day period is of interest. Pasteurization apparently does affect the heterotrophic organisms capable of oxidizing carbonaceous material such as CMC, in addition to inhibiting the nitrifying organisms.

It may be concluded from these results that seed pasteurization would not be a practical method for elimination of nitrification in studies of this kind, as it inhibits heterotrophic activity and thus yields lower BOD values, indicating less available carbonaceous material than is actually present.

Substitution of Nitrate for Ammonia

Addition of a completely oxidized nitrogen compound to BOD dilution water instead of ammonia should prevent nitrification from occurring. The question remains, however, as to whether nitrate can serve as a source of nitrogen in the oxidation of organic matter.

On the basis of tests with pure microbial cultures, nitrate has not been found to be a satisfactory supply for a great number of microorganisms. Because NH_3-N seems to be used more generally, NH_3-N was used as the source of nitrogen in BOD dilution water.

The seed used (sewage) in usual BOD work contains such a great diversity of species of microorganisms, it would seem highly unlikely that any of these would be capable of using nitrate-nitrogen while oxidizing an organic substrate and yielding a reliable BOD value.

Parallel tests with NH_3 and NO_3-N were conducted in order to determine the effect of the nitrogen source on the 5-day BOD of acetate. Table III presents the results obtained using the Warburg respirometer, in which 100 to 10,000 ppm acetate was the organic substrate. Also included in this table are the results obtained using all methods of oxygen-uptake measurement (standard, jug dilution, and Warburg) covering acetate concentrations of 2 to 10,000 ppm. Sewage was used as seed in all tests in a concentration of 0.1 to 10.0 per cent by volume. In another paper (3) it has been established that the three methods of BOD measurement and seed concentration within this range yield comparable 5-day BOD results with a given compound.

Nitrate-nitrogen gives results comparable with ammonia-nitrogen with

TABLE III.—Effect of Nitrogen Source on the 5-Day BOD of Acetate

Method	N Source	No. Samples	5-Day BOD (pts/pt)			
			Min	Max	Avg	Avg Dev.
Warburg	NH_3	3	0.74	0.76	0.75	±0.01
Warburg	NO_3	6	0.72	0.77	0.75	±0.02
All	NH_3	12	0.70	0.85	0.77	±0.03
All	NO_3	22	0.66	0.88	0.76	±0.04

TABLE IV.—Effect of Nitrogen Source on Cumulative Oxygen Demand of 8.0 ppm Acetate

Days	Nitrogen Source (parts O_2 consumed per part of acetate)			
	NH_4	NH_2	NO_4	NO_3
0	0	0	0	0
1.3	0.41	0.40	0.40	0.45
1.8	0.46	0.41	0.41	0.45
13.1	0.89	0.88	0.70	0.75
20.8	1.10	1.10	0.71	0.82

respect to the 5-day BOD values obtained with 2 to 10,000 ppm acetate. The average deviation in the samples tested with NO_3-N is slightly higher than with ammonia-nitrogen, but still remains within the commonly accepted error of 5 to 10 per cent for BOD tests.

Table IV gives the results of one experiment (jug method), in which the cumulative oxygen demand of 8.0 ppm acetate was measured for 21 days. Duplicate tests were run with both nitrogen sources, using 0.1 per cent sewage as seed. The dilution water with the nitrate-nitrogen was the same in all respects except the type of nitrogen compound used. Both dilution waters contained 0.6 ppm nitrogen.

Table IV also shows that with NO_3-N the average 21-day BOD is 0.77 part per part. This is in good agreement with the calculated and observed values reported elsewhere (3). With NH_3-N, however, the high average 21-day value (1.1 parts per part) indicates that nitrification has occurred. From these results, it is concluded that substitution of nitrate in BOD dilution water eliminates errors in observed BOD due to nitrification and makes possible the direct measurement of true carbonaceous BOD up to 21 days.

Table V shows the results of parallel tests to determine the effect of nitrogen source on the 5-day BOD of several other organic acids. The results with oxalic and ethylene-diaminetetracetic acids are comparable with the two nitrogen sources, although EDTA exhibited no BOD. On the other hand, nitrate does not seem to be a satisfactory nitrogen source for the organisms capable of oxidizing toluenesulfonic acid. This was the only instance where nitrate failed to give results comparable with ammonia. Further work along these lines is obviously needed

TABLE V.—Effect of Nitrogen Source on the 5-Day BOD* of Several Organic Acids

Acid		5-Day BOD with N-Source as			
Type	Conc. (ppm)	NH_3		NO_3	
		(ppm)	(pts/pt)	(ppm)	(pts/pt)
Oxalic	3.3	1.2	0.36	1.0	0.30
Oxalic	6.6	0.9	0.14	1.0	0.15
Oxalic	10.0	1.7	0.17	1.4	0.14
Toluene	3.3	1.5	0.45	0.4	0.12
Sulfonic	6.6	2.4	0.36	0.4	0.06
Sulfonic	10.0	2.1	0.21	0.5	0.05
Ethylene	3.3	0	0	0	0
Diamine	6.6	0	0	0	0
Tetracetic	10.0	0	0	0	0

* Standard dilution method, 0.1 per cent sewage.

and the purpose of this paper is to emphasize that need.

It may also be mentioned here that consistent and reliable BOD values have been obtained for other fatty acids (C_3-C_{10}) where nitrate was supplied as the sole nitrogen source in order to prevent nitrification during 20-day incubation periods (3).

Summary and Conclusions

It has been demonstrated that nitrification causes serious errors in BOD measurements on pure organic compounds where the test is continued beyond 5 days, and that nitrification must be prevented in some manner if reliable carbonaceous BOD values are to be obtained. The following are four methods of eliminating nitrification error from BOD tests which have been investigated:

1. Maintenance of a constant BOD: N ratio, leaving no excess oxidizable nitrogen other than that necessary for growth of the heterotrophic organisms.
2. Pasteurization of seed material to kill or inhibit the autotrophic nitrifying organisms.
3. Measurement of increased NO_2- and NO_3-N content during incubation and subtraction of nitrogenous oxygen demand from observed BOD values.
4. Substitution of a completely oxidized nitrogen source in the BOD dilution water.

On the basis of the results obtained from these investigations, it is concluded that:

1. By maintaining the expected BOD : N : P ratio at 100 : 5 : 1, nitrification will not occur, even up to 20 days of incubation, and the observed BOD values include only carbonaceous oxygen demand. The NH_3-N concentration is sufficient only for heterotrophic growth. No excess ammonia is available for oxidation to nitrate. This procedure is impractical, however, for the usual BOD test, because the approximate BOD of the substrate must be known in advance so that the NH_3-N concentration in the dilution water may be adjusted to fit this ratio.

2. The seed pasteurization procedure without reseeding does not selectively inhibit or kill nitrifying organisms, but it has a detrimental effect on the heterotrophic organisms responsible for oxidizing a carbonaceous substrate. Pasteurization of seed results in lower observed BOD values for a considerable period of the time necessary for redevelopment of the heterotrophic organisms. Pasteurization, however, appears to have no effect on the ultimate BOD of carboxymethylcellulose. This procedure, if adopted, would constitute an additional step in the BOD test. For these reasons, it is concluded that seed pasteurization is an unreliable and impractical method for eliminating nitrification in cumulative BOD measurements on pure organic compounds or industrial wastes.

3. The measurement of cumulative increases in NO_2- and NO_3-N content and subtraction of nitrogenous oxygen demand from observed BOD is a reliable method for obtaining true carbonaceous BOD. However, due to the amount of work involved, this method is not applicable to routine BOD tests where time and manpower factors must be considered.

4. Preliminary investigations have shown that the following results may be obtained by substitution of nitrate in BOD dilution water:

   (a) Supply of a satisfactory nitrogen source for the growth of organisms oxidizing the lower fatty acids, oxalic acid, and carboxymethylcellulose.
   (b) Prevention of nitrification up to a period of at least 20 days, therefore allowing for direct BOD measurements including only carbonaceous oxygen demand.

Acknowledgment

The study reported herein was supported by a grant from the United States Public Health Service, Division of Research Grants.

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2. Hurwitz, E., Barnett, G. R., Beaudoin, R. E., and Kramer, H. P., "Nitrification and BOD." *Sewage Works Jour.*, **19**, 6, 995 (Nov. 1947).
3. Gaffney, P. E., and Heukelekian, H., "Oxygen Demand of the Lower Fatty Acids." To be published in THIS JOURNAL, May 1958.
4. Butterfield, C. T., "Experimental Studies of Natural Purification in Polluted Waters." *U. S. Pub. Health Rep.*, **44**, 2865 (1929).
5. Orford, H. E., Rand, M. C., and Gellman, I., "A Single Dilution Technique for BOD Studies." THIS JOURNAL, **25**, 3, 284 (Mar. 1953).

MEETINGS OF INTEREST

1958

Apr. 13–18	**American Chemical Society,** San Francisco, Calif. R. M. Warren, American Chemical Society, 1155 16th St., N. W., Washington 6, D. C.
Apr. 18	**Annual Pennsylvania Clean Streams Conference,** Penn-Harris Hotel, Harrisburg, Pa. Pennsylvania State Chamber of Commerce, Harrisburg, Pa.
Apr. 20–25	**American Water Works Association,** Dallas, Texas. Harry E. Jordan, Secretary, AWWA, 2 Park Ave., New York 16, N. Y.
May 1–2 (Revised Dates)	**Seventh Southern Municipal and Industrial Waste Conference,** Duke University, Department of Civil Engineering, Durham, N. C.
May 5–7	**Thirteenth Industrial Waste Conference,** Purdue University, Lafayette, Ind. Professor Don E. Bloodgood, School of Civil Engineering, Purdue University, Lafayette, Ind.
May 18–24	**Inter-American Association of Sanitary Engineers,** San Juan, Puerto Rico. Enrique Ortega, Secretario General AIDIS, Associacion Interamericana de Ingenieria Sanitaria, Apartado de Correos 218, San Juan, Puerto Rico.
May 26–28	**Fifth Ontario Industrial Waste Conference,** Delawana Inn, Honey Harbour, Ontario. A. E. Berry, Ontario Water Resources Commission, East Block, Parliament Buildings, Toronto, Canada.
Jun. 22–25	**American Institute of Chemical Engineers,** Bellevue-Stratford Hotel, Philadelphia, Pa. F. J. Antwerpen, Executive Secretary, 25 West 45th St., New York 36, N. Y.
Jun. 22–28	**American Society of Civil Engineers,** Multnomah Hotel, Portland, Ore. W. H. Wisely, Executive Secretary, 33 West 39th St., New York 18, N. Y.

WASTE STABILIZATION PONDS

I. EXPERIMENTAL INVESTIGATIONS

By E. R. Hermann * and E. F. Gloyna

Respectively, Research Engineer, Sanitary Engineering Research Laboratory; and Associate Professor of Sanitary Engineering, University of Texas, Austin, Tex.

The design and operation of stabilization ponds strictly as waste-water treatment devices has been developed in the field largely on an empirical basis. Frequently, the outdoor environmental factors influencing the operation of the biological systems could not be controlled and, furthermore, there was no way of knowing which of these factors had the most effect. With the addition of a certain degree of laboratory control and a detailed statistical analysis of field data, a basis for design and operation has been developed and reported (1).

Herein the results of four years of experimental investigations employing laboratory models and outdoor pilot plants are reported. Laboratory experimentation was conducted under various environmental conditions. Both natural and synthetic substrates were employed as influent wastes. The effects of hydraulic phenomena such as recirculation and turbulent mixing were studied in relation to BOD loading and detention time.

In subsequent articles of this series, Part II will be devoted to an analysis of performance data and physical features of waste stabilization ponds

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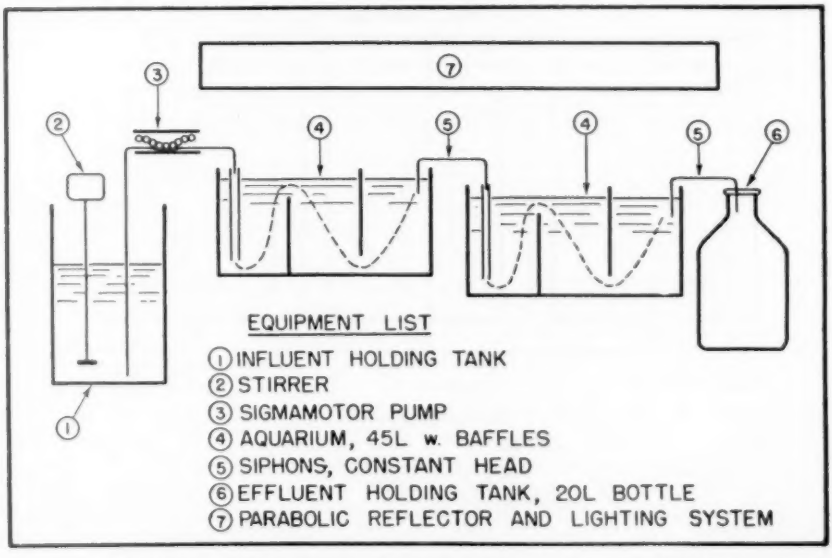
EQUIPMENT LIST
① INFLUENT HOLDING TANK
② STIRRER
③ SIGMAMOTOR PUMP
④ AQUARIUM, 45L w. BAFFLES
⑤ SIPHONS, CONSTANT HEAD
⑥ EFFLUENT HOLDING TANK, 20L BOTTLE
⑦ PARABOLIC REFLECTOR AND LIGHTING SYSTEM

FIGURE 1.—Laboratory model for continuous flow experiments.

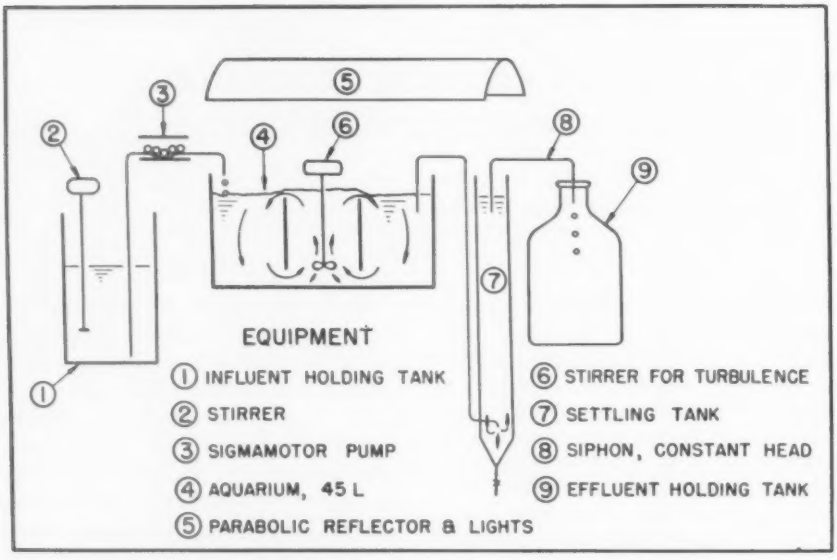

FIGURE 2.—Laboratory model—turbulent mixing experiment.

located at 188 communities throughout Texas, while in Part III design criteria will be developed.

Experimental work is presented in three sections: laboratory models—uncontrolled environment; laboratory models—controlled environment; and outdoor pilot-plant experiments. The

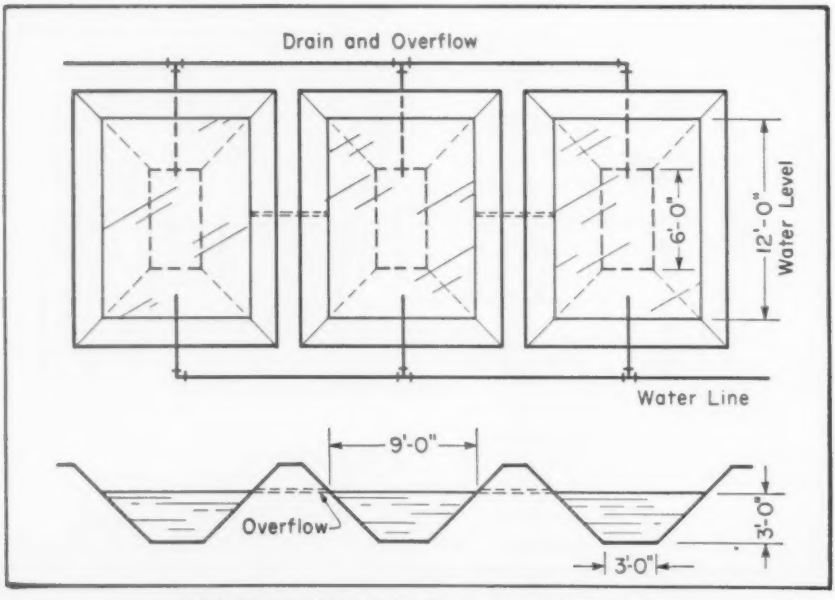

FIGURE 3.—Multi-basin waste stabilization ponds.

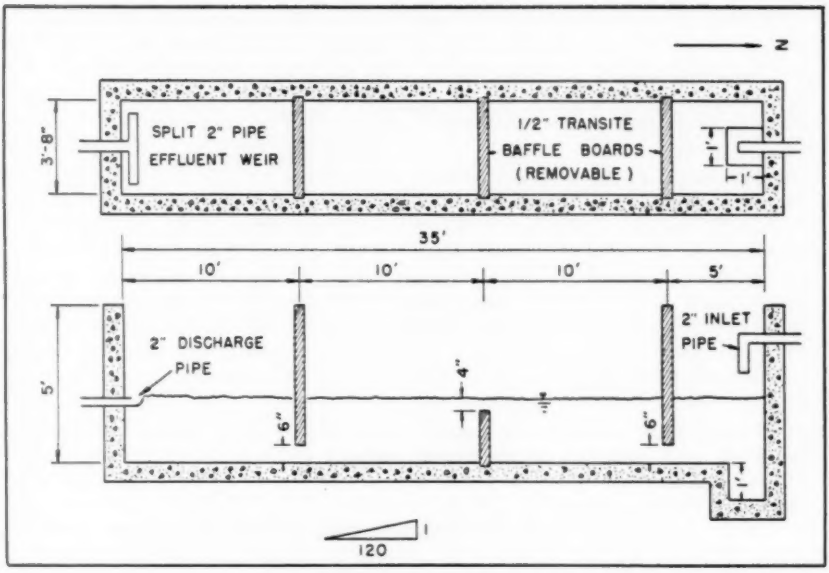

FIGURE 4.—Rectangular waste stabilization pond.

first group of experiments resulted mainly in delineation of the problems involved. The second group of experimental runs under controlled conditions, provided data from varying detention period, waste loading, recirculation, and turbulent mixing. Pilot plant investigations were used to test the effects of different operating depths and to determine the extent to which laboratory results would be duplicated in the field. Diagrams of typical experimental arrangements are shown in Figures 1, 2, 3, and 4.

Laboratory Models—Uncontrolled Environment

Two sets of three aquaria, each containing 45 liters of algae water, were arranged in series and exposed to outside weather conditions. Daily batch feeding with a synthetic substrate consisting of urea, peptone, beef extract, and essential salts produced the results shown in Table I. The mean influent 5-day BOD in Test No. 1 was 230 mg/l and represented BOD loadings of 515, 257, and 172 lb per acre per day for the cumulative surface areas of the 3 aquaria. Detention periods were successively 3.3, 6.7, and 10.0 days. BOD removal was high, ranging from 85 to 98 per cent. The residual BOD of the final effluent had a mean value of only 8 mg/l.

In comparing Test No. 1 with Test No. 2 it is noted that although the over-all detention is almost doubled in Test No. 2, a higher final effluent BOD was obtained. In other words, the BOD removal in Test No. 2 was smaller even though the detention period was longer and the total amount of organic feed and environmental conditions were identical. This phenomenon may be attributed to a considerable increase in algal population which occurred as a result of the increased detention. From this it may

TABLE I.—Aquaria Using Synthetic Sewage—Uncontrolled Temperature and Lighting*

Test No.	Length of Test (Days)	Sample Source (Aquarium No.)	Deten. (Days)	Turb. (mg/l)	Algae (Cells/μl)	BOD				Eff. pH
						Influent		Eff.	Removal	
						(mg/l)	(lb/acre/day)	(mg/l)	(%)	
1	50	1	3.3	—	173	230	515	34	85	8.0
	50	2	6.7	—	131	34	257	10	96	8.1
	50	3	10.0	—	315	10	172	8	98	8.7
2	93	1	6.7	570	1,200	210	235	27	87	9.5
	93	2	13.7	560	1,500	27	117	19	91	10.1
	93	3	20.0	640	1,100	19	78	16	993	10.1

* Synthetic sewage pH = 8.0.

be inferred that unnecessary algal blooms in the effluent of a waste stabilization pond should not be permitted.

Laboratory Models—Controlled Environment

In this group of experiments a synthetic waste, natural sewage, effects of recirculation, and effects of turbulent mixing were investigated.

Synthetic Substrate—Starlac

Experimental Conditions

Three laboratory models (Figure 1) were assembled, each consisting of two aquaria. The mean effluent rates from models A, B, and C were 16.6, 9.3, and 3.0 ml/min, respectively, and corresponding influent rates were 20.1, 12.8, and 5.7 ml/min. The discrepancies between influent and effluent rates were due to evaporative losses.

A light meter survey indicated that incident light intensities normal to the water surfaces ranged from 80 to 1,140 foot-candles (ft-c) with an average value of approximately 500 ft-c. The models were lighted by means of this arrangement for 13 hr out of each 24-hr period.

In anticipation of the possibility of using a synthetic sewage on a larger scale, wherein the cost of such items as peptone, castile soap, and urea might be prohibitive, a simple substrate was developed. The synthetic substrate contained non-fat dry milk solids (Starlac), dibasic potassium acid phosphate, tap water, and sewage seed.

The theoretical BOD of the Starlac powder was calculated to be 658 mg/g and the empirical BOD later proved to be very close to the theoretical value. Therefore, to obtain 250 mg/l of BOD in a liquid dispersion a concentration of 380 mg/l of Starlac was required. This in turn provided 6.6 mg/l of phosphorus and 22 mg/l of nitrogen. The K_2HPO_4 supplemented the phosphorus and potassium content and also buffered the pH so as to avoid the isoelectric range of such a constituent of Starlac as casein.

TABLE II.—Average Analysis—Synthetic Substrate

BOD (mg/l)	250.0
Total phosphorus (P) (mg/l)	11.1
Soluble phosphorus (P) (mg/l)	7.9
Total nitrogen (N) (mg/l)	19.7
NH_3—N (mg/l)	0.2
Org. N (mg/l)	19.5
Soluble N (mg/l)	18.0
Soluble org. N (mg/l)	18.0
Median pH value	8.0
pH range	9.5–6.5

Adequate dispersion of the liquid feed was maintained during the 24-hr period between batches. Addition of sewage seed and tap water insured presence of indigenous organisms and trace elements. Average analytical values obtained are given in Table II.

The temperature of the waste water in the aquaria was dependent upon the ambient temperature in the laboratory and absorption of radiant energy from the light sources suspended over the aquaria. Although the maximum temperature in the laboratory was 21.8°C and the average daily minimum was 17.8°C, the aquaria temperature cycles varied from 21°C at 0800 hr when the lights were turned on, to 33°C at 2,100 hr just before the lights were extinguished.

During the "shakedown" period it was noted that the contents of the aquaria tended to stratify and that scum consisting of dead and live algal cells accumulated at the water-air interface, thus preventing absorption of light energy into the underlying culture. As a result the aquaria receiving the greater BOD loadings soon became anaerobic and the bacterial-algal culture become predominantly bacterial. This observation indicated that prevention of scum formation is desirable for effective pond operation. In full-scale ponds the formation of scum is partially inhibited by wind and wave action; therefore, jets of air from 2-mm ID glass-capillary tubes were directed obliquely onto the aquaria surfaces so as to create small surface currents. These currents were apparently confined to the top 1 or 2 cm of aquarium depth, since subsequent thermometric measurements relative to depth still showed the existence of temperature stratification in the liquid medium.

The controlled factors, *i.e.*, light, temperature, flow rates, nutrient concentrations, and "wind" were consistent during the experimental run. Based upon the mean influent rates the detention periods for models A, B, and C were 3.1, 4.8, and 10.6 days, respectively.

Analyses were made on the influent waste, effluent from each model, and filtered effluents, all on a continuing basis. The filter medium used throughout this group of experiments was "Celite 535," made from diatomaceous earth. This filter medium was chosen because of its desirable characteristics for algae filtration as indicated by previous experimental work. Therefore, it should be borne in mind that the criterion employed for defining soluble phosphorus, soluble nitrogen, or BOD in filtered effluents, is dependent primarily upon the fractional separation of particles, colloids and ions afforded by the filter medium acting on a certain fluid substrate.

In addition to the above, a survey of each aquarium for DO and pH was made at the end of the experimental run. The DO survey encompassed one 24-hr cycle and was related to time, temperature, and depth of sample withdrawal. The pH survey consisted of a single group of observations with respect to depth.

BOD Results

The BOD of the effluents from the laboratory units was low, considering the loading. The unfiltered BOD varied between 10 and 40 mg/l in model A; 5 and 20 mg/l in model B; and 5 and 20 mg/l in model C. The BOD of the filtered effluents was about 50 per cent of the unfiltered suspensions. This 50 per cent ratio appeared to be a consistent value as verified in several other experiments. The daily variation of the effluent BOD's is shown in Figure 5. All BOD concentrations are "crude" values, *i.e.*, they have not been corrected for evaporative losses.

Nitrogen and Phosphorus

The mean nitrogen values of the influent waste were 0.2 mg/l ammonia N, 19.5 mg/l organic N, 19.7 mg/l

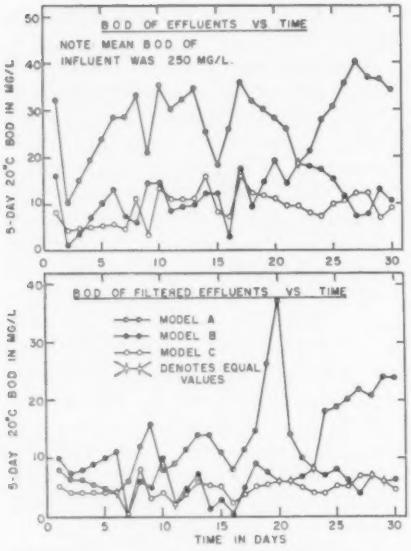
BOD OF EFFLUENTS VS TIME
NOTE MEAN BOD OF INFLUENT WAS 250 MG/L.
5-DAY 20°C BOD IN MG/L
BOD OF FILTERED EFFLUENTS VS TIME
MODEL A
MODEL B
MODEL C
DENOTES EQUAL VALUES
TIME IN DAYS

FIGURE 5.—Daily effluent BOD—Starlac.

total N, and 0.24 mg/l nitrate N. The daily filtered and unfiltered values for nitrogen in the effluent, with the exception of nitrate N, are presented in Figures 6 and 7. The nitrate concentrations in the effluents were less than 0.2 mg/l. No significant changes or trends were indicated by this particular analysis throughout the experimental run. However, the consistently low nitrate N concentration obtained in the effluents of all three models leads one to suspect that bacterial-algal systems such as the ones under study may be conservative of nitrates and would be useful in the treatment of high nitrate wastes. The relative trends of the various nitrogen components are also apparent. Although the graphical form of the data indicates that a steady state has been reached, failure to recover as much nitrogen from the effluents as was provided by the influent shows that either nitrogen was being lost to the atmosphere or deposition was occurring in the aquaria. In the latter possibility, retention of material may have been in the form of settled solids, suspended solids, and even stratified solutions having different densities. To provide a true correlation between influent and effluent values, the effluent results were corrected for evaporative

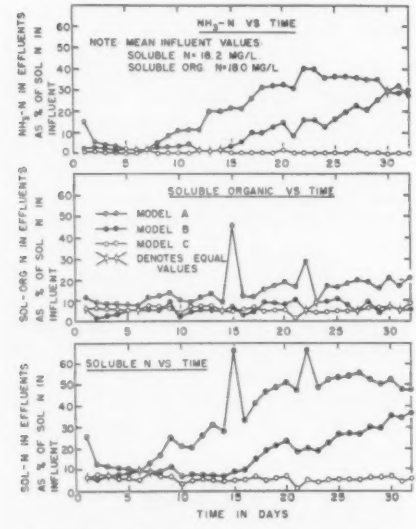
NH3-N VS TIME
NOTE MEAN INFLUENT VALUES
SOLUBLE N= 18.2 MG/L
SOLUBLE ORG. N=18.0 MG/L
NH3-N IN EFFLUENTS AS % OF SOL. N IN INFLUENT
SOLUBLE ORGANIC VS TIME
MODEL A
MODEL B
MODEL C
DENOTES EQUAL VALUES
SOL.-ORG N IN EFFLUENTS AS % OF SOL. N IN INFLUENT
SOLUBLE N VS TIME
SOL.-N IN EFFLUENTS AS % OF SOL. N IN INFLUENT
TIME IN DAYS

FIGURE 6.—Nitrogen concentrations in filtered effluents—Starlac.

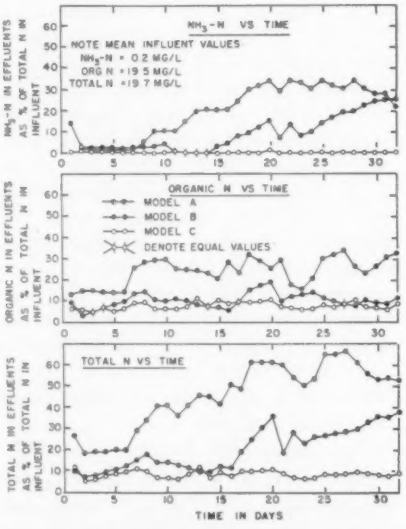
NH3-N VS TIME
NOTE MEAN INFLUENT VALUES
NH3-N = 0.2 MG/L
ORG N = 19.5 MG/L
TOTAL N = 19.7 MG/L
NH3-N IN EFFLUENTS AS % OF TOTAL N IN INFLUENT
ORGANIC N VS TIME
MODEL A
MODEL B
MODEL C
DENOTE EQUAL VALUES
ORGANIC N IN EFFLUENTS AS % OF TOTAL N IN INFLUENT
TOTAL N VS TIME
TOTAL N IN EFFLUENTS AS % OF TOTAL N IN INFLUENT
TIME IN DAYS

FIGURE 7.—Nitrogen concentrations in effluents—Starlac.

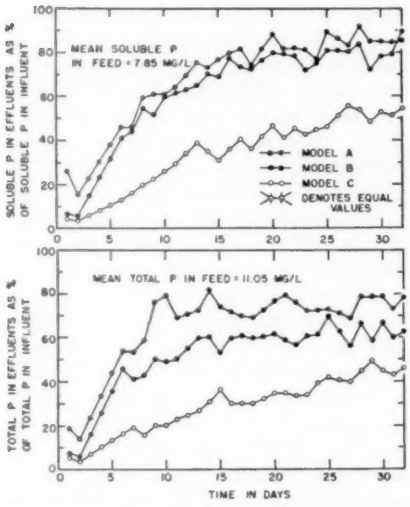
SOLUBLE P IN EFFLUENTS AS % OF SOLUBLE P IN INFLUENT
MEAN SOLUBLE P IN FEED = 7.85 MG/L
MODEL A
MODEL B
MODEL C
DENOTES EQUAL VALUES
TOTAL P IN EFFLUENTS AS % OF TOTAL P IN INFLUENT
MEAN TOTAL P IN FEED = 11.05 MG/L
TIME IN DAYS

FIGURE 8.—Phosphorus concentrations in effluents—Starlac.

losses. Diatomaceous earth filtration of the effluents resulted in removals of the remaining total nitrogen of 23, 24, and 45 per cent, respectively, in models A, B, and C.

The influent waste had mean concentrations of 7.85 mg/l soluble P and 11.05 mg/l total P. The daily effluent values are shown in Figure 8. Of the three nutrient parameters (BOD, N, and P), the phosphorus determinations were the most consistent.

The trends of the curves showing total phosphorus in the effluents indicate that models A, B, and C had reached steady conditions after about 10, 13, and 30 days, respectively. The duration of this test was 32 days. The fact that the phosphorus recovery neither reached nor exceeded unity (100 per cent) indicated that the steady conditions were not absolute, and that, as in the case of nitrogen, organic and inorganic phosphorus compounds were being lost from the liquid system or retained in the aquaria. Observation of the soluble phosphorus data shows that the attainment of a steady state in both A and B models was delayed in time or shifted to the right when compared to total phosphorus data. This observation suggests that there might have been a conversion of insoluble phosphorus compounds to soluble compounds by the bacterial components of the biological system, and that the latter soluble phosphorus compounds were most readily utilized by the algae to build new cells during the first 15 to 20 days of the experimental run. The soluble phosphorus in model C effluent might have just reached the aforementioned temporary steady condition, when the run was terminated.

Algae

All three model stabilization ponds, operating under quiescent conditions, had proportionately few algae carried out in the effluent. Based solely upon occasional grab samples, it was estimated that the algae concentrations in the various aquaria ranged from 100 to 1500 cells/μl. The information contributed by this particular analysis was that most of the algae in all three models were retained. This phenomenon was attributed to the physical properties of the experimental apparatus and mode of operation.

The predominant genus of algae in the effluents of models B and C was *Scenedesmus*. The genus *Oocystis* was also present in appreciable numbers and at the very end of the experimental run *Euglena* was the most prevalent in the A aquaria. In the B and C aquaria, mats of filamentous algae formed from time to time; however, these organisms were not found in the effluents, due to their surface collection while the outlet was located beneath the surface.

Dissolved Oxygen

At the end of the Starlac run a dissolved oxygen survey of the six aquaria was performed. Samples were carefully siphoned from the top, middle, and bottom levels of each tank and analyzed for DO. The above pro-

cedure was repeated hourly for 24 hr. The temperature at the point of withdrawal of each sample was also measured to provide a basis for calculation of oxygen saturation. Figure 9, illustrating the DO concentrations in model A, shows that no measurable DO was produced in Aquarium A_1; however, a faint surface bloom was observed daily in this tank starting about 4 hr after the lights were turned on and persisting until after they were extinguished at 2100 hr. Any oxygen liberated by these algae evidently was immediately utilized by the bacteria for oxidation. In tank A_2 both the top and middle samples contained DO after 11 hr of illumination. Shortly after the lights were turned off the DO level again dropped to zero. Although the above-mentioned concentrations of oxygen in solution were quite small, it should be noted that the mid-depth samples contained more oxygen than the surface samples. This phenomenon supports the idea that the free-swimming algae stratify and select an optimal level relative to light intensity, provided quiescent conditions are maintained. Anaerobiosis was quite pronounced in the bottom samples from both A_1 and A_2, as evidenced by liberation of H_2S during the acidification step of the Winkler Test. The limited algae population, however, served a very useful function in that it prevented the entire tank from becoming septic, maintained a desirable pH condition, and limited the development of an odor problem.

The DO survey of model B is depicted by Figure 10. No measurable DO was produced in aquarium B_1 during the 24-hr observation period; however, oxygenation of the water in aquarium B_2 was actively carried out by the algae to the extent that the top and middle strata were supersaturated during 8 of the 13 hr of irradiance. The DO concentration of the bottom stratum showed considerable variation, probably due to agitation and pick-up of anaerobic sediments during the sampling procedure. The rapid deoxygenation produced by shutting off the lights should be noted. As in aquaria A_1 and A_2 the anaerobiosis in the bottom of aquarium B_1

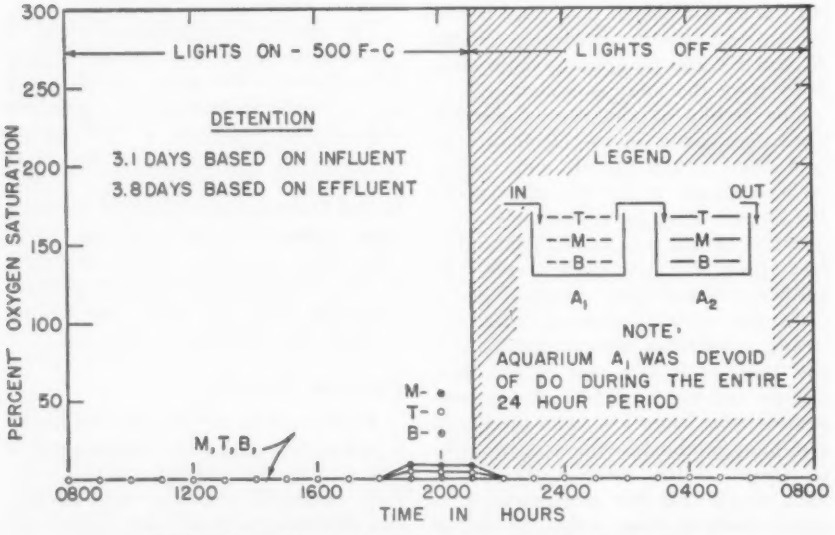

FIGURE 9.—Dissolved oxygen survey—Model A—Starlac.

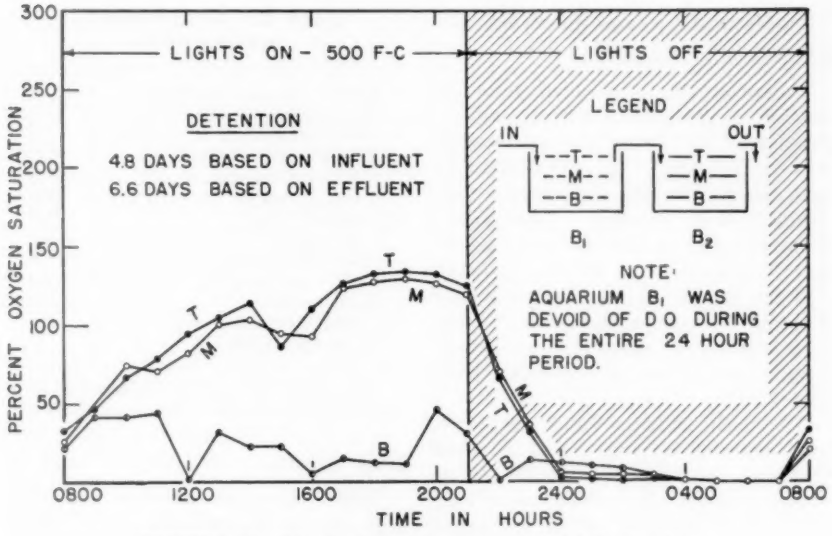

FIGURE 10.—Dissolved oxygen survey—Model B—Starlac.

had progressed to the stage where sulfates were being reduced to sulfides. In tank B_2 this anaerobic condition was apparent only between the hours of 0400 and 0700.

In model C (Figure 11) both aquaria produced oxygen. Aquarium C_1 was aerobic for a period of time corresponding to the illuminated fraction of the 24-hr cycle while aquarium C_2 not only remained aerobic throughout the period of observation, but was supersaturated in the top and middle strata for more than 13 hr.

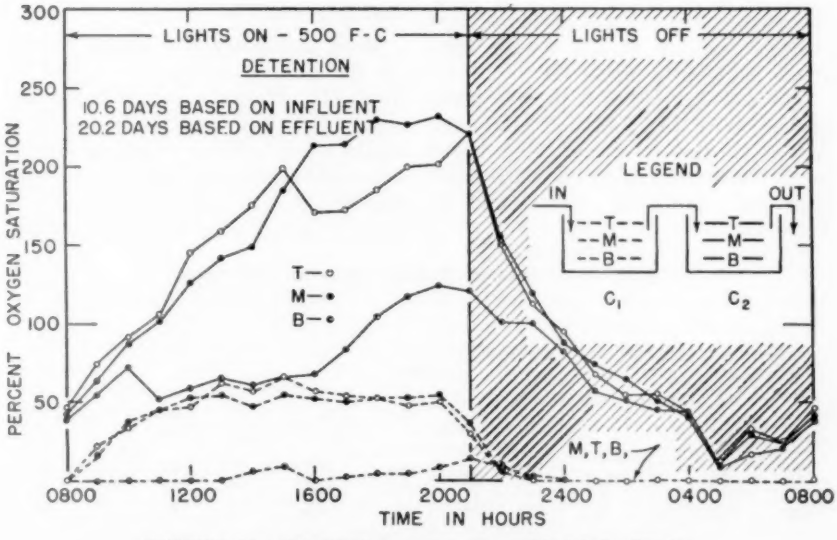

FIGURE 11.—Dissolved oxygen survey—Model C—Starlac.

Natural Sewage Substrate

Experimental Conditions

Following the controlled tests involving a synthetic substrate, an experimental run using domestic sewage was undertaken. In preparation of this experiment, the six aquaria were drained and cleaned. The liquid from the aquaria was combined, mixed into a homogeneous batch, analyzed, and returned to the aquaria as starter material for the sewage run. Light and wind were simulated as before. Temperatures varied between 25°C and 33°C.

The mean influent rates were 18.6, 11.6, and 5.3 ml/min for A, B, and C units, respectively, and the corresponding mean effluent rates were 17.2, 9.5, and 3.5 ml/min. Thus, the ratios of effluent to influent were 0.922, 0.823, and 0.650 in A–B–C order. These values were used as coefficients in evaporation loss corrections.

Raw sewage was obtained daily, settled for approximately 15 min, strained through a 16-mesh screen, and fed at different rates to each of the three models. To eliminate settling of solids in the influent holding tank, a mechanical stirrer was provided. An average analysis of the sewage substrate is given in Table III.

The detention periods for the three models were 3.4, 5.3, and 11.2 days for A, B, and C, respectively, based on the mean influent rates. BOD loadings and results are summarized in Table IV.

TABLE III.—Average Analysis—Sewage Substrate

BOD (5-day, 20° C) (mg/l)	310.0
Total phosphorus (P) (mg/l)	12.9
Soluble phosphorus (P) (mg/l)	6.8
Total nitrogen (N) (mg/l)	53.9
NH_3-N (mg/l)	31.5
Org. N (mg/l)	22.5
Soluble N (mg/l)	42.9
Soluble org. N (mg/l)	11.4
Total solids (mg/l)	671.0
Fixed matter (%)	49.0
Optical density*	0.35
Soluble optical density	0.12
Median pH value	7.7

* Using 1.8 cm cylindrical cuvettes and 410 mμ light in a Lumetron Colorimeter, Model 401.

BOD Results

Based upon the BOD of the effluents, the model oxidation ponds were very effective in stabilizing the sewage. The average BOD removals were 91, 93, and 96 per cent for models A, B, and C, respectively. Filtration of the suspended matter from the effluents further removed 25 to 35 per cent of the remaining BOD. In many cases the BOD of the filtered effluent was less than 10 mg/l.

Nitrogen and Phosphorus

Mean nitrogen values obtained daily on the influent sewage are given in Table III. Plotted curves indicate that steady state had been reached in each of the three models. Computations of material balances for total N are shown in Table V. Failure to recover all of the nitrogen in the liquid phase of the

TABLE IV.—Laboratory Models—Controlled Environment*

Length of Test (Days)	Deten. (Days)	pH		BOD							
				Influent				Effluent		Removal	
		Infl.	Effl.	Min (mg/l)	Avg (mg/l)	Max (mg/l)	Avg (lb/acre/day)	Filt. (mg/l)	Unfilt. (mg/l)	Filt. (%)	Unfilt. (%)
22	3.1	7.7	7.7	144	310	410	263	22	29	93	91
22	4.8	7.7	7.8	144	310	410	168	16	21	95	93
22	10.6	7.7	8.2	144	310	410	75	8	12	97	96

* Austin, Texas sewage.

biological system was most likely due to loss into the atmosphere. This assumption seems valid since during part of each 24-hr period a portion of each model was void of DO. Denitrification under these conditions will progress according to the schema $NO_3^- \rightarrow NO_2^- \rightarrow N_2$. Effusion of N_2 from the liquid contents of the aquaria could easily account for the total nitrogen loss, especially since pH values from 7.6 to 8.2 predominated in the middle and upper regions. To illustrate, it may be calculated that the nitrogen effusion from the surface of model A need only have averaged 144 μg/sq cm/day. The effluent nitrogen results were all adjusted for evaporative losses so as to provide correlation with the influent values.

Filtration of the effluents through diatomaceous earth removed 12, 23, and 31 per cent of the residual total nitrogen from the A, B, and C effluents, respectively.

The mean concentration of total phosphorus in the sewage fed to the aquaria was 12.92 mg/l, of which 6.75 mg/l (52 per cent) was soluble P. Other than a general increase in both total and soluble P with passage of time, it appears impossible to attach any significance to the trends of phosphorus increase. Material balances for total P showed recoveries for the liquid phase of 80, 74, and 69 per cent for models A, B, and C, respectively. Greater loss of phosphorus with increased detention lends credence to the idea that effusion of phosphorus from the models in such compounds as hydrogen phosphide may have taken place. An accounting of the quantities of soluble P into and out of the system indicates considerable conversion of total P to soluble P and at the same time supports the above mentioned concept of loss of phosphorus to the atmosphere as a function of time.

TABLE V.—Material Balances for Total Nitrogen Using Austin Sewage

Model	Total N In (g)	Total N Out (g)	N Recovery (%)
A	75.7*	52.1†	69
B	47.7	24.4	51
C	22.5	11.0	49

* Nitrogen in aquaria at beginning of run—1.0 g; nitrogen in waste fed into system—74.7 g.
† Nitrogen in effluent from system—40.3 g; nitrogen in aquaria at end of run—11.8 g.

TABLE VI.—Algae Counts from Laboratory Models Using Austin Sewage

Aquarium	Algae Count (Cells/l)	Predominant Genus	Other Genera
A_1	56	*Phacus*	*Scenedesmus*
A_2	210	*Scenedesmus*	*Phacus*
B_1	120	*Phacus*	*Scenedesmus, Euglena*
B_2	150	*Phacus*	*Scenedesmus, Euglena*
C_1	300	*Scenedesmus*	*Phacus*
C_2	340	*Scenedesmus*	*Phacus*

Algae

The initial stock contents of all six aquaria had an algae count of 780 cells/μl, *Scenedesmus* predominating. At the end of the experimental run unicellular algae were counted from the representative samples of the aquaria contents and are shown in Table VI.

All samples also contained some filamentous organisms (uncounted) such as *Oscillatoria* and *Sphaerotilus*, as well as numerous bacteria and small protozoa. The latter were especially prominent in A_1 and A_2. Comparatively few algae were carried out in effluents, primarily because the effluent was withdrawn from a point located two cm below the surface. Daily algae counts of the effluent from model A ranged from 0 to 340 cells/μl with a mean value of 19 cells /μl. The minimum, mean, and maximum values for model B were 0, 35, and 135 cells/μl, while corresponding observations for model C were 0, 30, and 182 cells/μl. At the beginning of the experimental run the predominant genus in all three effluents was *Scenedesmus*. On the 13th

day *Phacus* became dominant in the A effluent; it was not until the 27th day, however, that *Phacus* predominated in the B and C effluents. Mats of filamentous blue-green algae formed in the aquaria from time to time, but were not found in the effluents. Ability of the algae present to congregate at an optimal stratum was illustrated by sampling at different depths.

Dissolved Oxygen

A dissolved oxygen survey was made on each of the six aquaria a few days before the end of the experimental run. No measurable DO was produced in aquarium A_1; any oxygen liberated by the algal cells evidently was utilized immediately in bacterial oxidation. In tank A_2 the top level showed a trace of DO after 10 hr of illumination. Anaerobic conditions in nearly all of the A_1 and A_2 samples were indicated by liberation of H_2S upon acidification. On the other hand, the contents of A_1 had a stable pH value of about 7.2 and for samples taken at various depths in A_2 the range of pH from more than 90 observations was 7.4 to 7.9.

No measurable DO was produced in aquarium B_1 during the 36-hr observation period; in contrast, oxygenation of aquarium B_2 was well developed in the top and middle strata during the "lighted" hours, although the bottom samples of B_2 contained no DO. During this survey most of the samples of model B containing no DO liberated H_2S upon acidification. The pH range for B_1 was 7.4 to 7.9, for B_2, 7.5 to 8.1.

In model C the DO concentration followed the same patterns. It should be noted that no DO was obtained in bottom samples from either aquarium. As in models A and B, most of the zero DO samples from model C liberated H_2S when acidified. The pH range in C_1 was 7.3 to 7.8, and in C_2 ranged from 7.7 to 8.4.

Solids

The mean concentration of total solids in the sewage fed to the aquaria was 671 mg/l, of which 49 per cent was fixed matter. The total solids concentrations of the effluents, as shown in Figure 12, gradually increased during the first four weeks of the experimental run. After the 28th day all three models appeared to have reached

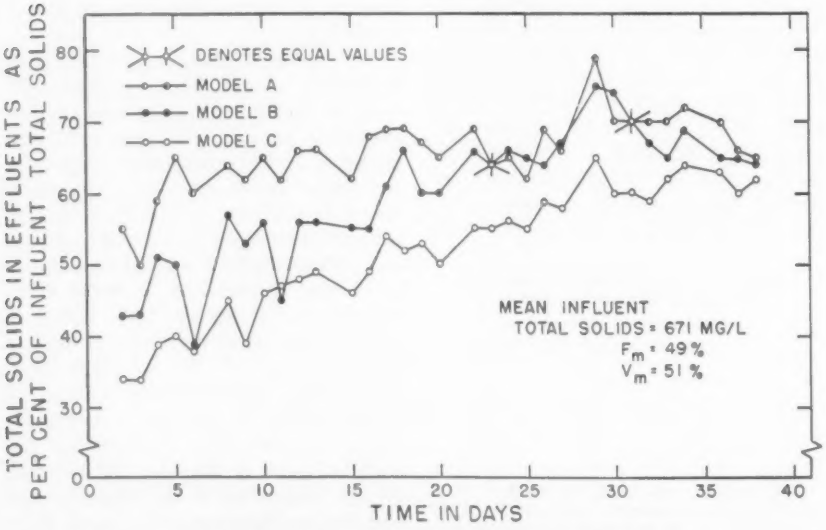

FIGURE 12.—Total solids in effluents—sewage.

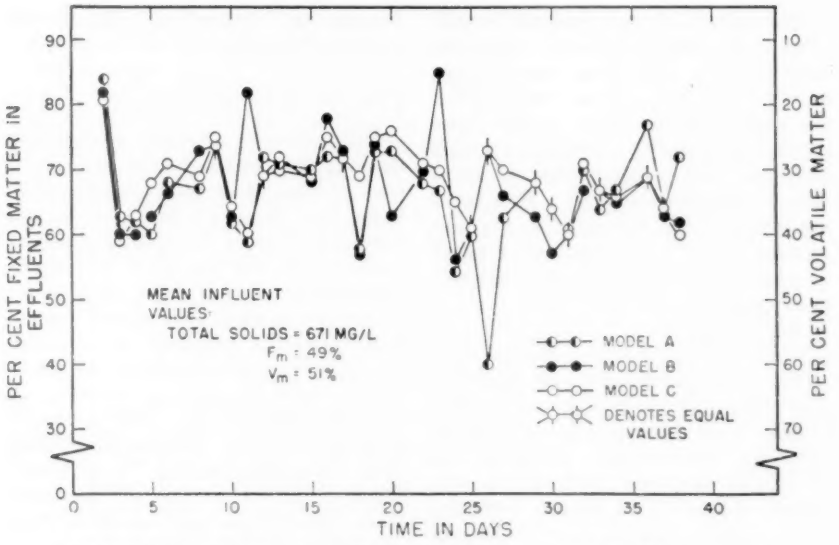

FIGURE 13.—Fixed and volatile portions of effluent total solids—sewage.

steady conditions with respect to total solids. The relative proportions of fixed and volatile matter in the effluents were plotted in Figure 13. The variations in these graphs are interpreted as being due to the vagaries of this particular analysis. The trends of all three graphs have zero slopes; thus mean values of the per cent fixed matter should be representative of the entire experimental run. The values were: A, 66 per cent; B, 67 per cent; and C, 68 per cent. Final total solids values were all adjusted for evaporative losses. Calculations of material balances for total solids indicated recoveries of 80, 80, and 90 per cent, respectively, for models A, B, and C.

TABLE VII.—Material Balance for Fixed Solids in Laboratory Models Using Austin Sewage

Model	In (g)	Out (g)	Recovery (%)
A	470	450	96
B	297	282	95
C	143	142	99

Material balances for fixed solids are shown in Table VII.

Recirculation Experiment

Experimental Conditions

Light, temperature, waste loading, and surface agitation were essentially the same for each of the three models. Recirculation was introduced as the factor to be tested and was provided by pumping from the effluent end of the second aquarium to the influent pipe of the first aquarium. The three models, designated as A, B, and C, were provided, respectively, with recirculation factors of 10, 5, and 2. The detention periods were about 5 days for each model. Other environmental conditions were similar to those previously discussed.

For purposes of control and comparison a synthetic substrate providing 200 mg/l of BOD was employed as the influent waste. This substrate was made from Starlac as previously used but in a lower concentration. The BOD loading was approximately 107 lb per acre per day for each model.

The controlled environmental conditions and influent nutrients varied less than ± 5 per cent from the average values reported. Flow rates when averaged over a 24-hr period were quite close to the final average, although shut-downs or pump failures of 10 to 60 min duration occurred. Graphs of the effluent chemical constituents and physical properties indicate that about 23 days were required before the systems reached a steady state.

BOD Results

The mean BOD values of the effluents after the models reached equilibrium were 6, 4, and 4 mg/l for A, B, and C, respectively. Compared to single pass treatment, recirculation improved the BOD reduction; however, it should be noted that the models having recirculation factors of 5 and 10 gave no better results than the model with a recirculation factor of only 2. The BOD results of the effluents before filtration are plotted in Figure 14. Filtration reduced the BOD still further.

Nitrogen and Phosphorus

Utilization of nitrogen was greater during the establishment phase of each culture than after steady conditions had been reached. This was especially true of the soluble nitrogen constituents. At the end of the experimental run, analysis of the algae water remaining in each model pond showed a considerable build-up or retention of nitrogenous compounds by comparison with the starting culture. A material balance for total nitrogen, however, showed recoveries ranging from 70 to 80 per cent. It is postulated that denitrification occurred from time to time with resultant effusion of N_2 to the atmosphere at the water surface. This loss of nitrogen was not as great as when recirculation was omitted. On the other hand, increasing the recirculation factor ap-

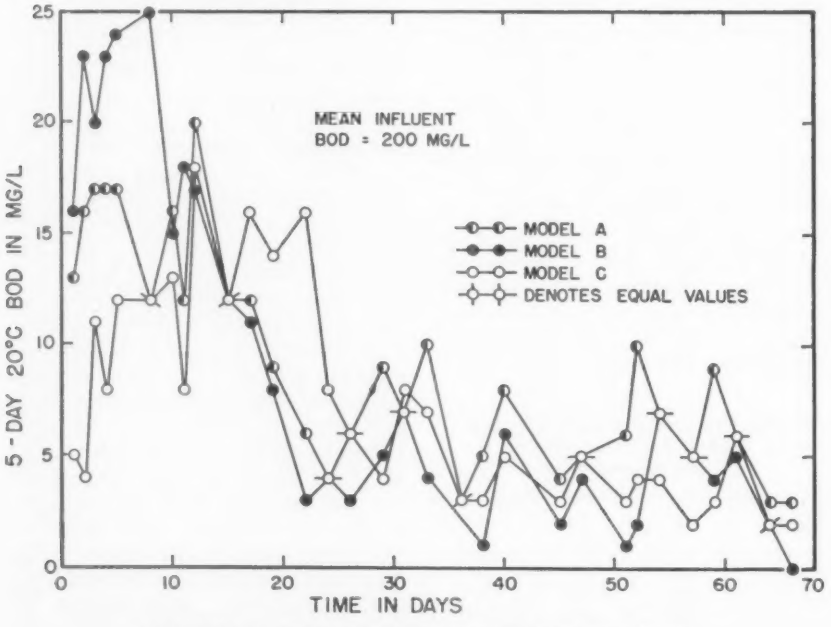

FIGURE 14.—BOD of effluents—recirculation experiment.

parently provided no greater nitrogen recovery or conservation in the system.

The graphs of total and soluble phosphorus concentrations in the effluents indicate that phosphorus passed through the models with very little utilization and at a uniform rate throughout the experimental period. Material balances gave the following results for total P:

Model	Total Phosphorus Recovery (%)	Recirculation Factor
A	79	10
B	82	5
C	94	2

By comparison with unrecirculated models the addition of recirculation *per se* to the systems apparently decreased the loss of phosphorus to the atmosphere. However, these results indicate that the greater the recirculation factor the greater the loss of phosphorus from the liquid system.

Solids

Material balances for the fixed solids into and out of each system indicated recoveries of 103, 94, and 111 per cent for models A, B, and C, respectively. The deviations from 100 per cent may have arisen from experimental error or, possibly in the case of high values, from the formation of carbonates from absorption of carbon dioxide from the atmosphere.

The total solids concentration of the influent waste was 458 mg/l, of which 37 per cent was fixed matter and 63 per cent volatile matter. At the beginning of the experimental run, from 80 to 95 per cent of the total solids appeared in the effluents; after 20 days of continuous operation the effluent levels of total solids had dropped to less than 50 per cent of the mean influent value where they remained in this region for the rest of the run. Accompanying this reduction in solids was a shift in the relative proportion of fixed and volatile matter so that the effluents during the last 50 days of the run contained only 25 per cent volatile matter and 75 per cent fixed matter.

Algae

The algae water used to start the experiment had an algae count of 231 cells/μl, predominantly *Scenedesmus* with a few *Phacus* present. Microscopic examination of the effluents made three times a week showed a wide variety of algal genera to be present, including *Phacus, Scenedesmus, Euglena,* and during the last part of the run, *Chlorella.* The counts from model A effluent ranged from 0 to 66 cells/μl with a mean value of 12 cells/μl. The minimum, mean, and maximum values for model B were 0, 15, and 117 cells/μl, and corresponding observations for model C were 0, 3, and 17 cells/μl. At the end of the experimental run representative samples of the aquaria contents had algae counts as follows with respect to unicellular free-swimming forms: A_1, 0; A_2, 10; B_1, 363; B_2, 528; C_1, 0; and C_2, 16 cells/μl. The predominant genus in B_1 and B_2 was *Chlorella;* in aquaria A_1, A_2, C_1, and C_2, however, the unicellular free-swimming forms were completely overridden by the filamentous genus *Oscillatoria.*

Dissolved Oxygen

The results of a dissolved oxygen survey are represented in Figures 15, 16, and 17. In model C with a recirculation factor of 2, no measurable DO was produced in aquarium C_1; any oxygen liberated by the algal cells evidently was utilized immediately in bacterial oxidation. In the second aquarium of this system, C_2, the top and middle strata were well oxygenated during the hours of illumination and although the concentration of DO in the bottom sample was not nearly so high, there was at least 14 per cent of oxygen saturation present even at the end of the dark portion of the diurnal cycle. It is especially significant that the DO in top, middle,

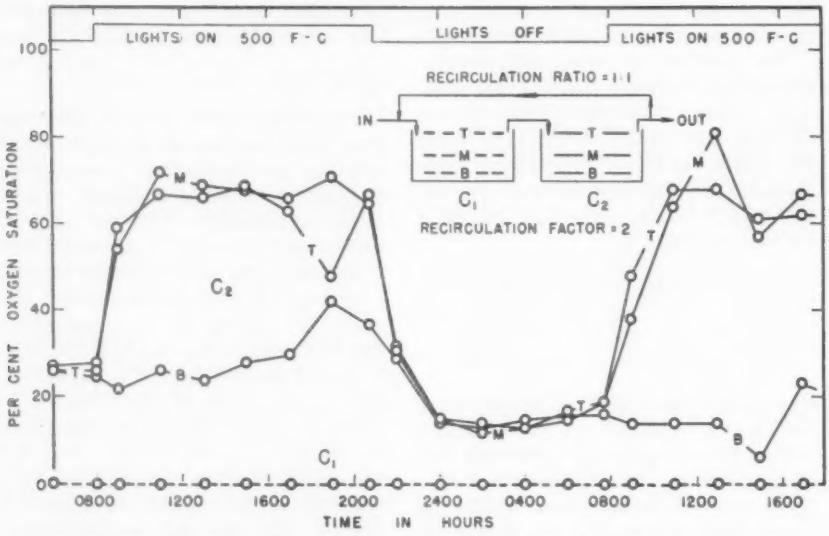

FIGURE 15.—Dissolved oxygen survey—Model C—recirculation experiment.

and bottom strata became equal shortly after the lights were turned off and maintained a positive oxygen reserve throughout the hours of darkness. In contrast to this, the DO level in similar experiments without recirculation dropped to zero in the second aquarium within a few hours after the lights were extinguished.

An interesting phenomenon took place in the operation of model B, which operated with a recirculation factor of 5. Dissolved oxygen from B_2, the second aquarium, was brought

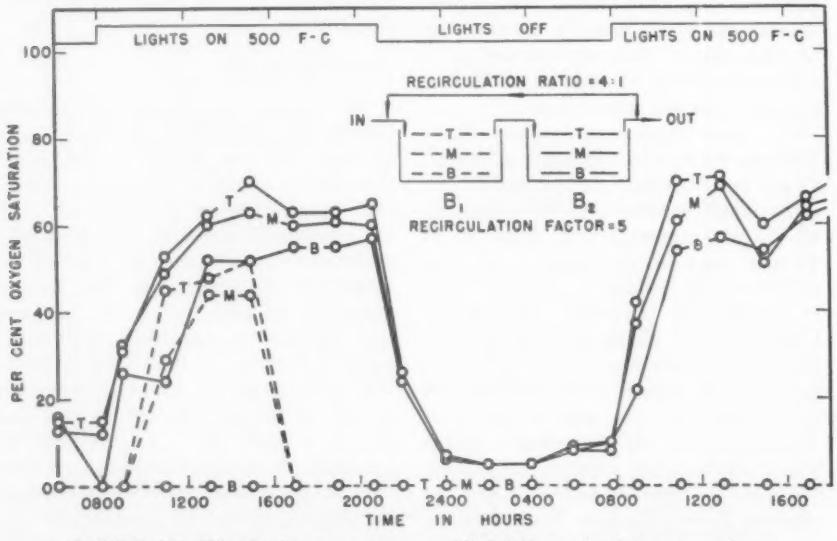

FIGURE 16.—Dissolved oxygen survey—Model B—recirculation experiment.

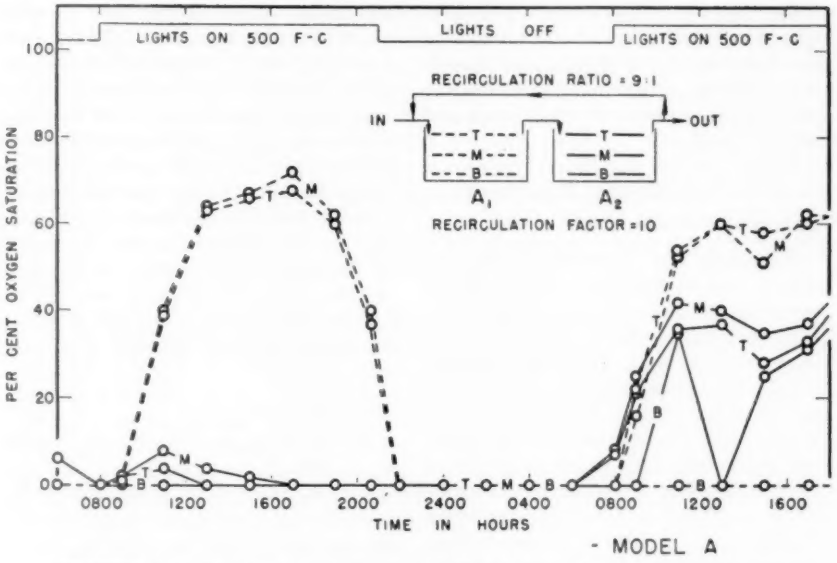

FIGURE 17.—Dissolved oxygen survey—Model A—recirculation experiment.

around to the first tank with the result that about 50 per cent oxygen saturation was reached in the top and middle strata during the "afternoon" hours. The bottom stratum, however, remained devoid of DO. The presence of DO in the first aquarium did not occur when no recirculation was provided nor did it occur when the recirculation factor was 2. It should be further noted that during the dark hours the level of the DO in the top, middle, and bottom strata of B_2 was appreciably lower than when the recirculation factor was 2. Thus the gain of DO in B_1 seems to have been at the expense of B_2. Due to the disturbance of the hydraulic pattern by sampling and shifting of the phases of the three periodic functions involved (detention, illumination, and recirculation), no DO appeared in the first tank when the survey was extended beyond a 24-hr period. If the hydraulic and lighting cycles are considered, *i.e.*, detention period = 5 days, recirculation factor = 5, and the lighting cycle = 1 day, it becomes apparent that at least transient synchronization must occur with the result that reinforcement in the cyclic production of oxygen by the algal cells must also occur.

Dissolved oxygen distribution in model A, having a recirculation factor of 10, shows a complete reversal of normal conditions relative to the first and second aquaria (Figure 17). Instead of the normal pattern in which higher concentrations of DO would occur in A_2 than in A_1, the reverse was true. In addition to the above it is seen that both aquaria were devoid of DO during most of the dark portion of the lighting cycle. As in model B_1 shifting of the phases of the three periodic functions, aggravated by sampling disturbances, decreased the DO level in A_1 and increased it in A_2 during the first portion of the second diurnal cycle plotted in Figure 17. The foregoing observations relative to model A tend to substantiate the hypothesis that reinforcement in the cyclic production of oxygen by algae in waste stabilization ponds is

a function of recirculation. This phenomenon should be of importance in the development of design and operating criteria, especially those dealing with the acceptance of shock loads and odor control.

Turbulent Mixing Experiment

Experimental Conditions

Although the purpose of the research was to find and develop better methods of accomplishing waste stabilization rather than to grow algae, it was felt that turbulent mixing should be investigated because of its apparent advantages in providing (a) a more uniform distribution of nutrient materials, (b) quick transfer of oxygen arising from both photosynthesis and surface absorption to lower depths, and (c) more efficient utilization of available algae as oxygenators due to the intermittent light effect. Accordingly, a turbulent mixing experiment was initiated using three laboratory models operating at detention periods of approximately 1.5, 3.0, and 5 days, designated as A, B, and C, respectively. These detention periods were based upon the mean influent rates which were: A, 19.3 ml/min; B, 12.5 ml/min; and C, 5.4 ml/min. The mean effluent rates were 0.995, 0.936, and 0.834 ml/min in A, B, and C order. These values were used as coefficients of reconstitution in evaporation loss corrections.

The environmental aspects such as lighting were similar to those previously discussed. The average maximum and minimum daily temperatures were 28°C and 22°C, respectively. Maximum hourly temperatures were 36°C. The influent synthetic substrate (Starlac) had a BOD of 207 mg/l.

A vertical or upflow settling tank, consisting simply of a piece of plastic tubing of appropriate diameter and length to provide a detention period of 2 hr, received the effluent from each aquarium. In addition to plain sedimentation, clarification was brought about by siphoning the effluent from a plane located about 2 cm below the water surface. It had been noticed in previous experiments that the free-swimming algal cells accumulated in a stratum some 5 to 10 cm beneath the water surface during the "daylight" hours (500 ft-c incident light) and rose to the surface during the hours of darkness. By drawing off the effluent from a point located beneath the surface and above the usual depth of the algae stratum, further separation was effected.

BOD Results

The BOD loadings of the three units were 338 lb per acre per day for model A, 210 lb per acre per day for model B, and 95 lb per acre per day for model C. The mean BOD concentrations in the unsettled samples drawn directly from the continuously agitated aquaria were 39 mg/l, 49 mg/l, and 19 mg/l for A, B, and C, respectively. Sedimentation tank effluents designated as A′, B′, and C′ contained 27, 26, and 14 mg/l of 5-day 20°C BOD. These are crude values, not corrected for evaporative losses. The length of the run was 50 days.

Nitrogen

The mean nitrogen values of the influent waste were 0.5 mg/l ammonia N, 15.2 mg/l Organic N, and 15.7 mg/l total N. No nitrate analyses were made because prior experiments had indicated that nitrate concentrations would be of no significance under the conditions of this experimental run. Samples taken directly from the aquaria and from the sedimentation tanks are represented in relation to time. Data on nitrogen constituents show that turbulent mixing results in the system reaching steady conditions with respect to metabolism much more readily than with quiescent flow. However, material balances calculated from analyses of the initial and final aquarium contents and from the in-

fluent and effluent waste waters of the aquaria showed an over-all loss of nitrogen from all three models, although there was a net gain in ammonia N at the expense of Organic N in all three cases. In general, as the BOD loading increases (shorter detention period) there is a corresponding increase in the denitrification of Organic N to ammonia N.

Algae

The initial stock contents of the aquaria had an algae count of 1,815 cells/μl in model A, 165 cells/μl in B, and 693 cells/μl in C. *Chlorella* and *Oocystis* were mainly present. The algae were fairly abundant and varied widely in population density. *Chlorella* was by far the most predominant algal genus observed in both the aquarium and settled effluent samples during the entire experimental run; however, euglenoids and other genera became more abundant during periods when the algae counts were low. Although maximum populations of 850 cells/μl, 3,650 cells/μl, and 3,400 cells/μl occurred in A, B, and C, respectively, the counts at the end of the experiment were only 343 cells/μl, 544 cells/μl, and 218 cells/μl in representative samples obtained after freeing all slimes from the walls and homogenizing the aquarium contents of each model. Although environmental conditions were adequately controlled, the population of free-floating algae had declined considerably. No apparent reason for this behavior was found.

Dissolved Oxygen

The results of the dissolved oxygen survey, made on each aquarium at the end of the experimental run are shown in Figures 18, 19, and 20. The detection of even small amounts of free oxygen in solution in model A was considered encouraging in view of the BOD loading (338 lb per acre per day) and detention period (1.5 days). Although aquarium A was devoid of DO almost 65 per cent of the time, there was no indication of H_2S production upon acidification of the hourly samples. This phenomenon is held to be quite significant and will be discussed in the concluding article of this series. The contents of model A

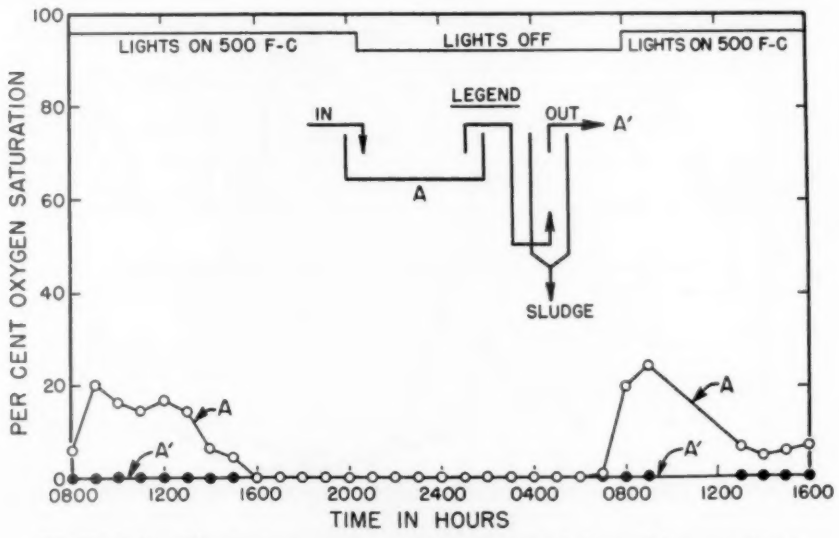

FIGURE 18.—Dissolved oxygen survey—Model A—turbulent mixing experiment.

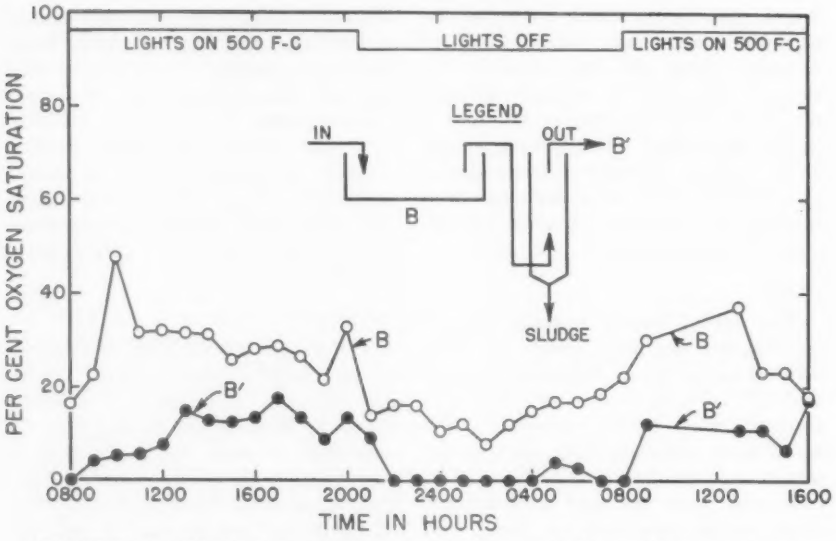

FIGURE 19.—Dissolved oxygen survey—Model B—turbulent mixing experiment.

had a stable pH value of 7.3 during the survey period.

The DO concentrations that occurred in model B are shown in Figure 19. It is of interest to note the moderating effect of turbulent mixing and the carry-over of DO from the aquarium effluent to the settling tank effluent. As in the more heavily loaded model A, the pH value was very stable, ranging from 7.4 to 7.5, and tests for H_2S were negative.

In model C the DO concentrations were quite high and remained above

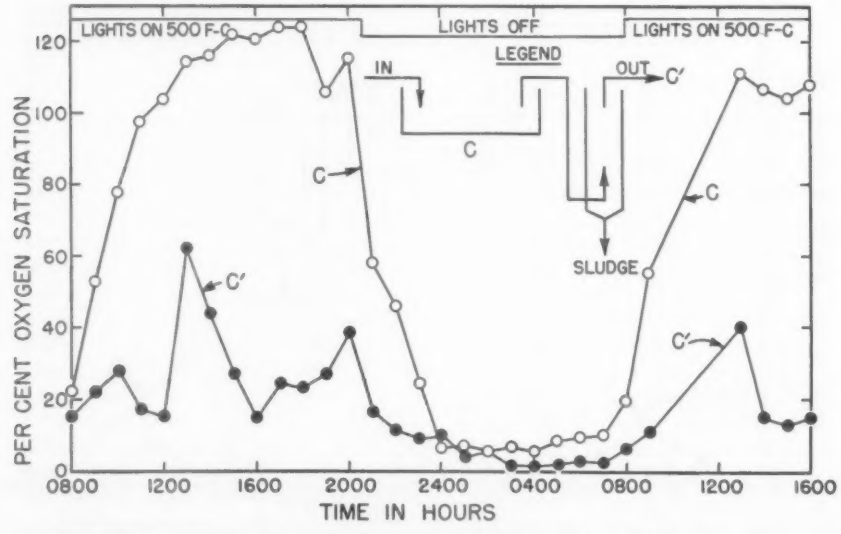

FIGURE 20.—Dissolved oxygen survey—Model C—turbulent mixing experiment.

TABLE VIII.—BOD Reduction in a Rectangular Oxidation Pond, 35 Ft Long, 4 Ft Wide, 2 Ft Deep, Containing Settled Sewage

Run No.	Deten. (Days)	pH		BOD			
		Infl.	Effl.	Infl. (mg/l)	Infl. (lb/acre/day)	Effl. (mg/l)	Removed (%)
1	20	7.2	9.1	98	27	18	82
2	10	7.0	7.8	98	54	27	72

zero during the entire cycle. During 8 hr of the 12.5-hr illumination period the pond contents were supersaturated. As expected, there was no evidence of sulfide production. The pH values in this model, unlike the other two, showed a definite diurnal variation. At 0800 hr the pH was 7.4 and rose steadily to a value of 8.2 when the lights were turned off at 2030 hr. Within an hour the pH value had dropped back to 7.4.

Outdoor Pilot-Plant Experiments

As another step toward developing design and operating criteria for waste stabilization ponds, two outdoor pilot plants were used. One consisted of three series-connected pyramidal basins, each having a capacity of 1,200 gallons. The other pilot plant was a long rectangular concrete tank oriented with its long axis in the North-South direction.

Batch Loading

The results of preliminary studies are summarized in Tables VIII and IX. The pilot ponds were batch fed on a daily draw-off and make-up basis. The influent waste water was atypical of domestic sewage since it was obtained from an Imhoff tank receiving a highly variable research laboratory waste. Known waste sources include human excreta, animal excreta and feed waste, and chemistry and physics laboratory drainage. Differences in BOD loading were considerably greater than would ordinarily be expected and the waste water probably contained many substances not amenable to biological treatment.

Continuous Loading with Recirculation

Experimental Conditions

A pilot-plant study was conducted between June and Aug. of 1955, using the rectangular pond. With the depth

TABLE IX.—BOD Reduction in Series-Connected Oxidation Ponds*

Run No.	Deten. (Days)	pH		BOD			
		Infl.	Effl.	Infl. (mg/l)	Infl. (lb/acre/day)	Effl. (mg/l)	Removed (%)
1	6.7	7.1	9.5	106	63	32	70
2	13.4	9.5	10.2	32	42	27	75
3	20.0	10.2	10.3	27	21	25	77

* Three rectangular tanks with sloping walls; average depth approximately 2 ft; each tank—1,200 gal.

maintained at 2 ft, the tank had a liquid volume of 7,800 l. A detention period of 5 days was used and 1,554 l per day of synthetic sewage were fed during the 70-day run. A recirculation factor of 6.4 was employed. Temperatures, pH values, flow data, and algae counts were recorded daily. Samples for the remaining laboratory analyses such as BOD, nitrogen and phosphorus constituents, total solids, and optical density were collected three times per week. Evaporation losses were 12.2 per cent; therefore, the reconstitution factor was 0.878. Synthetic sewage having a BOD of 140 mg/l was provided. Thus, the loading on the pilot pond was 163 lb per acre per day..

The weather during this experimental run was hot and dry with the exception of 4 or 5 showers. There were no periods of prolonged cloudiness. Resultant analyses of the tank contents and the effluents indicated that the operating processes were erratic under these uncontrolled conditions.

BOD Results

The mean BOD of the effluent from this pilot plant was 27 mg/l; however, observed values ranged from 9 mg/l to 58 mg/l. Comparison of the time plot for BOD (Figure 21) with the daily log on pond conditions and predominant genus of algae present, indicates an interrelationship between the three. Algal blooms resulting in scum formation seemingly were responsible for the variations exhibited here, and apparently occur in cycles.

Nitrogen and Phosphorus

Analysis of plain and filtered effluents during the 70-day run produced the nitrogen results recorded in Figures 22 and 23. There is a marked resemblance of the graphs for both total N constituents and soluble N constituents to the graph for BOD. Utilization of nitrogen was greater during those phases when scum was controlled and greater photosynthetic oxygenation was taking place. Calculation of a

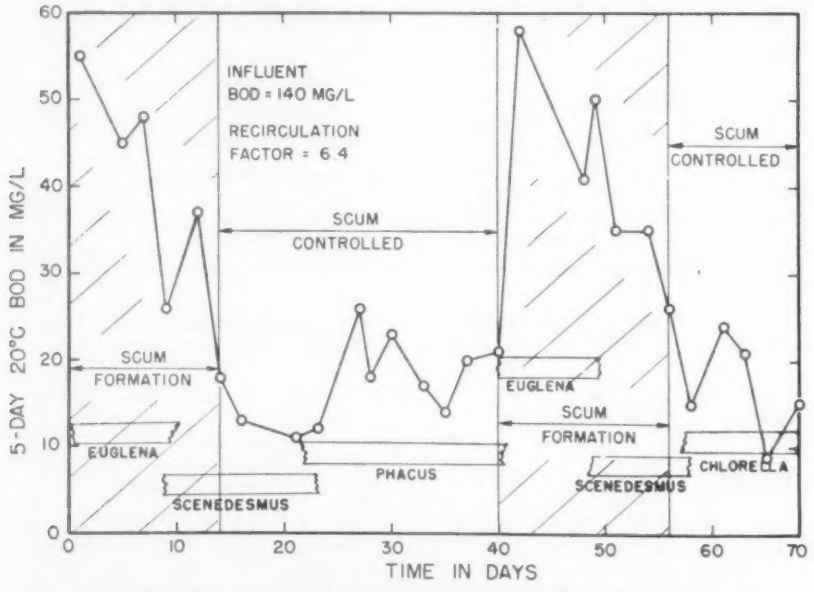

FIGURE 21.—BOD in effluent—pilot plant with recirculation.

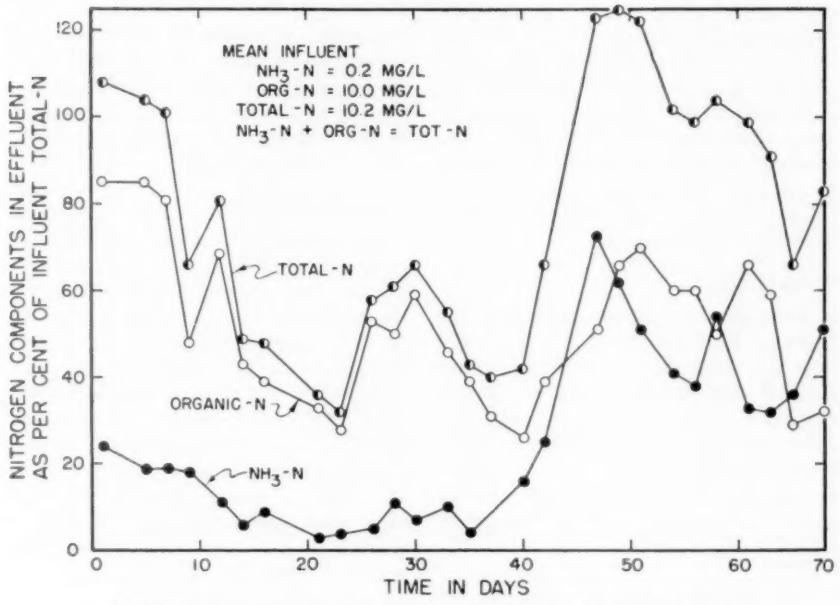

FIGURE 22.—Nitrogen in effluent—pilot plant with recirculation.

material balance for total N indicated that of the 1,193 g of N contained in the starter material and the feed, 962 g were recovered in the effluent and the final tank contents. The nitrogen recovery was 80.6 per cent.

Graphs of total P and soluble P concentrations in the effluent (Figure 24)

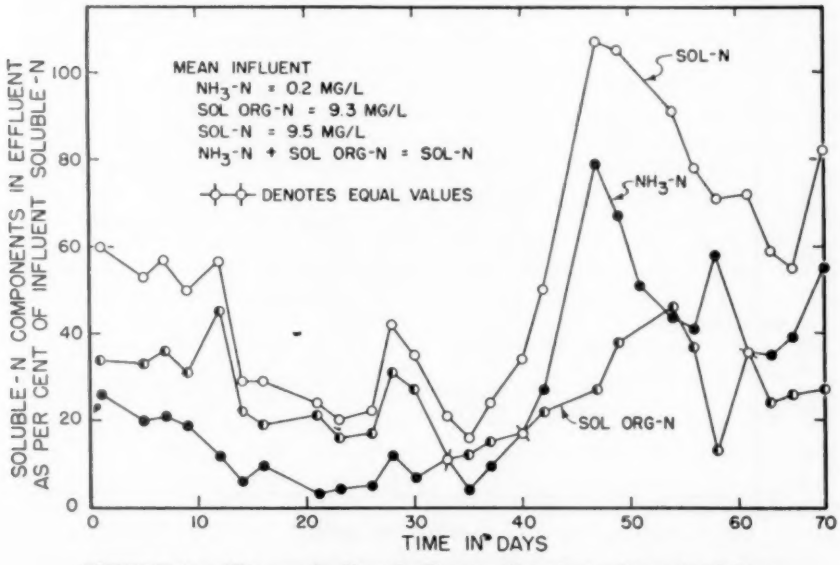

FIGURE 23.—Nitrogen in filtered effluent—pilot plant with recirculation.

show that there was little over-all utilization of phosphorus by the system. It should be noted, however, that uptake of phosphorus paralleled results for BOD and N in regard to pond cycles and scum formation. The material balance for soluble P showed a recovery of 94 per cent; while a similar balance for total P resulted in 87 per cent recovery.

Total Solids

The influent waste contained 365 mg/l of total solids, of which 48 per cent was fixed matter. The concentration of total solids appearing in the effluent from the pond was fairly uniform during the experimental run, with a mean value of 495 mg/l (corrected for evaporation) and showed neither a positive nor negative trend.

Algae

The starter material used in the pilot pond had an algae count of 667 cells/μl, mainly *Euglena* and *Scenedesmus*. During the experimental run the predominant genus shifted from *Euglena* to *Scenedesmus* to *Phacus* to *Euglena* to *Scenedesmus* and finally to *Chlorella*. Numbers of algae per unit volume as counted in samples from the pilot plant and the effluent are plotted in Figure 25. The algae count of the tank contents at the end of the run was 564 cells/μl.

Temperature and pH

The average minimum daily temperature of the influent waste was 30°C. The corresponding value for the tank contents and effluent was 27° C. The average maximum daily temperature of the influent waste was 36°C while the tank contents reached only 31°C. The effluent had the same temperature as the latter value. Deviations from the foregoing values during the course of the experiment were not significant. The effluent pH had a median value of 7.7 and a narrow range of from 7.5 to 8.5.

Effects of Different Depths

Experimental Conditions

During the period of July to August 1956 an investigation of pilot waste

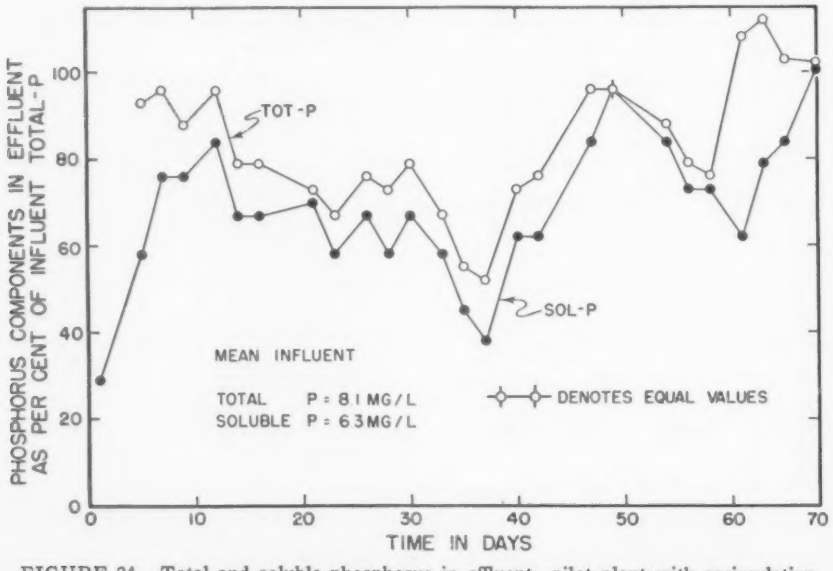

FIGURE 24.—Total and soluble phosphorus in effluent—pilot plant with recirculation.

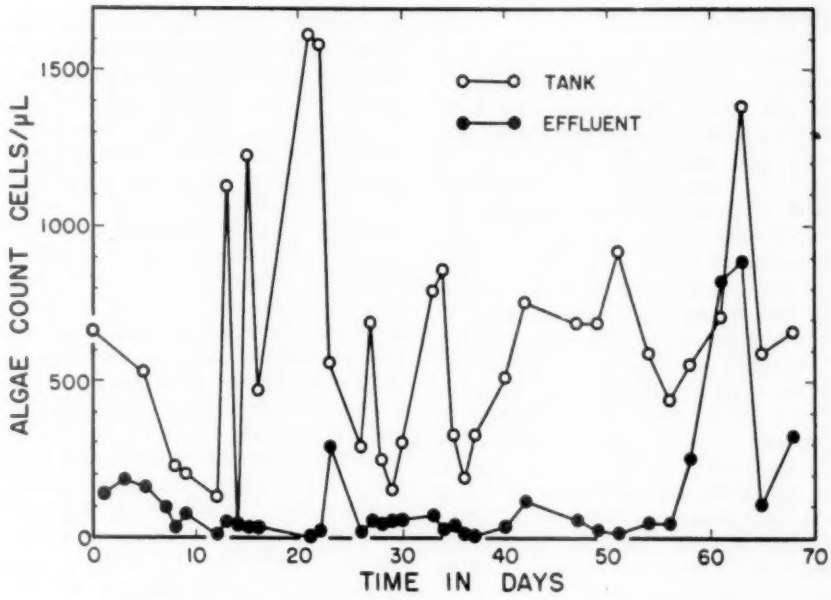

FIGURE 25.—Algae in pond and effluent—pilot plant with recirculation.

stabilization ponds operating at three different depths was conducted. For this purpose the long rectangular concrete pond was divided into thirds and ballasted with sand in two of the sections so as to provide three pilot ponds that were identical except for depth. It should be noted that the surfaces of the ponds were all at the same level so that light and wind conditions would be similar. One pilot plant was operated at a depth of 2 ft, one at 3 ft, and one at 4 ft. These were designated as A, B, and C, respectively. So that the three ponds would have the same detention period of 5 days, they were fed at the following rates: A, 328 ml/min; B, 512 ml/min; and C, 759 ml/min. Evaporative losses were 13.1, 8.4, and 5.7 per cent from A, B, and C, respectively. Thus, the corresponding coefficients of reconstitution were 0.869, 0.916, and 0.943 for A, B, and C.

The synthetic waste water, as in several of the previous experiments, consisted mainly of dried milk powder and tap water. The BOD of this influent waste water was about 200 mg/l for all three ponds; however, due to the different hydraulic loadings required to provide the same detention period in all three ponds, the BOD loadings were 217, 336, and 498 lb per acre per day for ponds that were 2, 3, and 4 ft in depth, respectively.

During the experimental run of 30 days the pilot ponds were fed daily. Control of scum formation was accomplished by submergence into the pond whenever noticeable amounts appeared. Measurements of flow rates, temperatures, pH values, and dissolved oxygen concentrations were made daily. Analyses made three times per week included algae count, ammonia N, organic N, total N, soluble N, BOD, optical density, and surface tension. Weather conditions were hot and dry with the exception of one day of heavy rain and one additional day of overcast sky.

BOD Results

After steady state conditions were reached the unfiltered effluent samples of the three pilot plants had mean BOD values of approximately 93, 187, and 212 mg/l for ponds A, B, and C, respectively; corresponding BOD analyses of filtered effluents produced values of 44, 112, and 123 mg/l. Removal of BOD was therefore only 54 per cent in pond A, 6 per cent in B, and minus 6 per cent in pond C, if no algae separation was effected. Separation of algae from the effluent waste water by filtration gave removals of 78 per cent, 44 per cent, and 38 per cent for A, B, and C. Apparently the two deeper ponds were not capable of accomplishing the degree of oxidation that took place in pond A, where a depth of only 2 ft and a correspondingly lower surface loading of BOD were encountered.

Nitrogen

Utilization of all nitrogen constituents was greatest during the breaking-in period. For the three ponds, steady-state conditions with respect to nitrogen metabolism seemed to have occurred between the 14th and 19th day of operation. Nitrogen metabolism did not remain steady, however, and excess stored nitrogen was released in the effluent of ponds B and C as the high side of their biological cycle was entered. In contrast, pond A apparently was retaining nitrogen in bottom sediments and/or losing it to the atmosphere by denitrification. Calculation of material balances for total N supported these observations. The nitrogen recovery values were 82, 108, and 117 per cent for A, B, and C, respectively. The recoveries greater than 100 per cent in the deeper two ponds indicate the possibility of nitrogen fixation by bacteria such as Azotobacter. According to Wilson and Werkman (2) these bacteria can fix 100 to 150 mg N per liter per day under optimum conditions. Carbohydrates, however, are necessary to their metabolism and the fixation of nitrogen

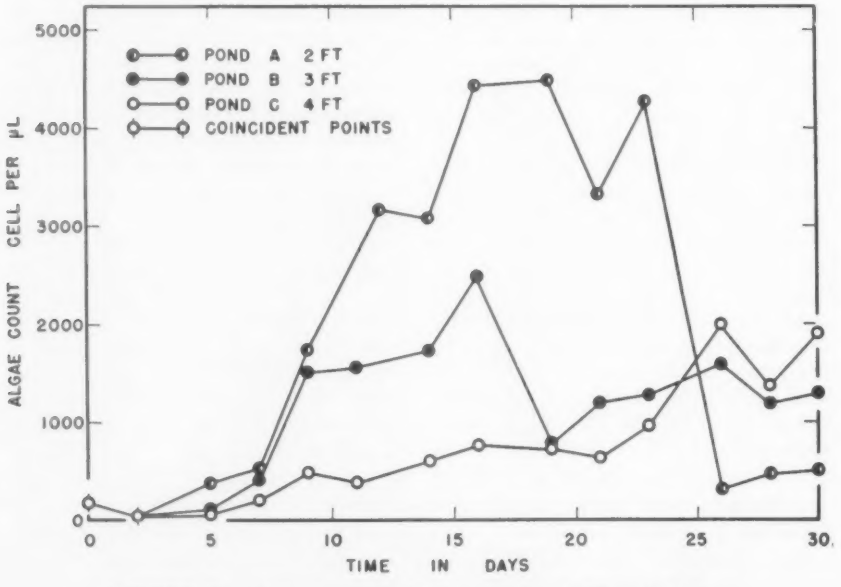

FIGURE 26.—Algae count of effluents—ponds at different depths.

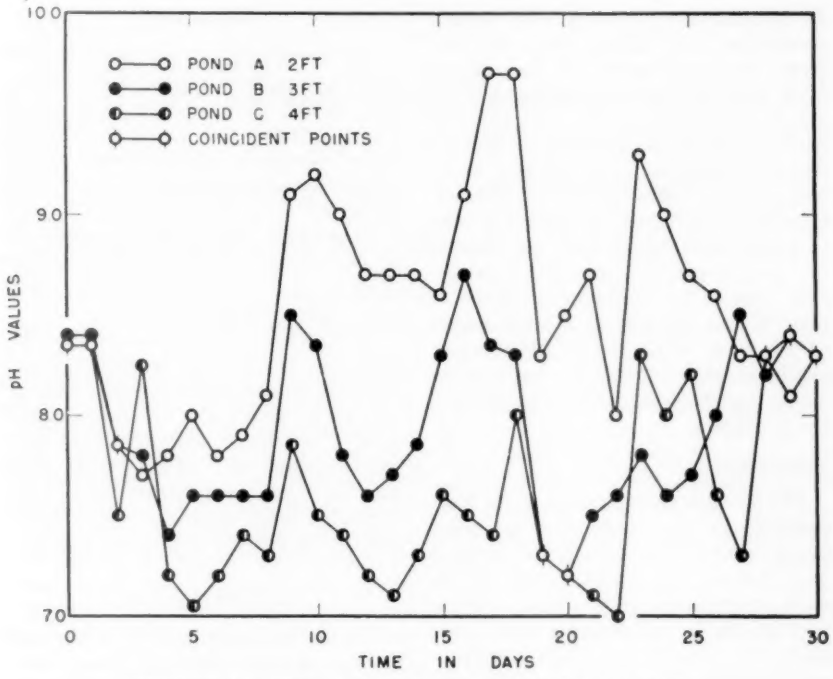

FIGURE 27.—Effluent pH values—ponds at different depths.

is limited to about 15 to 20 mg/g of CH_2O. Other organisms such as the bacterium *Rhodospirillum rubrum* and certain algae of the family *Cyanophyceae* are also capable of fixing nitrogen, but not in the quantities necessary to account for the nitrogen gains in ponds B and C.

Algae

The initial liquid media placed in the ponds contained an algal concentration of about 170 cells/μl. Effluent algae counts are shown in Figure 26. At the start of the run the predominant genus in all three pilot plants was *Scenedesmus*. After eight days *Chlorella* became dominant in the effluent of pond A and remained so until the end of the run. In pond B effluent, *Chlorella* became the more abundant organism during the 14th through the 19th days and then *Scenedesmus* returned as the dominant organism. *Lepocinclis* also was present in appreciable numbers. More *Scenedesmus* cells appeared in the effluent of pond C than any other genus during the 30-day run, except for the period from the 14th to the 26th day when *Lepocinclis* was predominant.

Dissolved Oxygen

Measurement of dissolved oxygen concentrations in samples from the three sections of each pond were made daily at 0900 and 1400 hr throughout the experiment. No DO occurred in the morning samples taken from ponds B and C. The morning sampling of pond A also was devoid of DO in the first two sections. The third, or effluent section, however, showed from 0.4 to 3.0 mg/l of DO present in 16 of the 30 days; on the remaining 14 days the DO was zero.

The afternoon samplings showed an entirely different picture. By 1400

hr considerable photosynthetic oxygen production had taken place and extreme supersaturation of the effluent from pond A was quite common. The algae in ponds B and C, with two and three times the BOD loading, did not liberate nearly as much oxygen to solution. The influent and middle sections of pond A had DO values similar to those from the effluent. In pond B the middle section contained considerably less. The influent sections of pond C had zero DO on all but 3 days of the run, while the middle section exhibited concentrations considerably lower than those shown in the plot for the C effluent.

Temperature

The average daily minimum air temperature in the vicinity of the pilot plant was 23°C during the experimental run; the average daily maximum temperature was 38°C. Variation in water temperature was more moderate. The average daily minimum and average daily maximum pond temperatures were 28°C and 32°C, respectively. Deviation of daily maxima and minima from the above mean values was very small during the experiment (generally less than ± 1.0° C).

pH Data

Graphical presentation of daily pH values of the effluents is given in Figure 27. Measurements of the pH value of samples taken from the middle and influent sections of each pond were practically the same as the effluent samples. The correlations between pH, pond depth, efficiency of treatment process, and algae count should be noted.

Summary

The results of experimental investigations have been reported for laboratory models and outdoor pilot plants using natural and synthetic sewages under specified environmental conditions. Various physical, chemical, and biological tests were employed for obtaining both direct and parametric measurements. Material balances were used as an analytical tool for gaging pond performance.

The results indicate that waste stabilization ponds may be designed and operated so as to accomplish all of the functions provided by conventional sewage treatment plants. With adequate operational control, BOD loadings may be much higher than those currently being applied in practice, especially in the warmer areas.

Acknowledgment

The research was partially sponsored by the Atomic Energy Commission, Sanitary Engineering Group, Mr. A. E. Gorman and Dr. J. A. Lieberman directing.

Express gratitude is extended to the members of the Sanitary Engineering Research team, Balcones Research Center, University of Texas, for their assistance during the four years of pilot plant operation.

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REMEMBER OCTOBER 6–9, 1958

Annual Meeting, Federation of Sewage and Industrial Wastes Associations, Sheraton-Cadillac Hotel, Detroit, Michigan

Industrial Wastes

1957 INDUSTRIAL WASTES FORUM *

Solving the Cooling Tower Blowdown Pollution Problem

L. L. HEDGEPETH, *Leader*

Staff Consultant, American Cyanamid Co., New York, N. Y.

Chairman Hedgepeth:—In planning this forum there were some ideas that may warrant review. One thing was that in the discussion period we will broaden the base of this discussion to include not only the disposal of waste waters from the operation of cooling towers but the disposal of all sorts of waste waters from water processing operations. In other words, when we process water for industrial use we get waste water, and it is a poorly explored part of the stream pollution problem. We have looked at manufacturing wastes; we have looked at wash-up; but the pollution problem resulting from processing of water itself in industrial plants has received scant attention, and it is our intention this morning to explore that problem within the time limits and capabilities of this discussion.

We have no prepared papers. Each member was selected as an expert in the particular line to which a phase of this discussion has been assigned. Audience participation is requested and is even essential to get this subject discussed properly.

Following each panelist's discussion we will open the meeting to a general discussion and then will proceed to the next phase of the topic.

My duty will be to delineate this problem as the panel views it. Dr. Riley will discuss types of treatment which are commonly used to process water in industrial plants so that the water may be used, or the equipment in which the water is circulating will not be corrosively attacked. Mr. Garrett will discuss the regulatory implications of the several pollutants outlined in the discussion. Mr. Gibson will outline a unique method of how the problem can be totally solved.

Before we move into that I think that some explanation should be offered to the audience of why this topic was selected. At the Texas Water and Sewage Short School last March a full day was devoted (morning, afternoon and evening) to a theoretical or hypothetical plant with a number of water supply and pollution control problems; the object being to have the group as a whole solve a complex and perplexing theoretical problem.

Mr. Gibson and I were on the panel that joined in that discussion. The panel had great difficulty in keeping away from the cooling tower. Much to my surprise some of the people in the audience stated that the cooling tower blowdown took more of their attention than maufacturing waste itself. Dr. Riley, our cooling tower and waste treatment specialist, agreed that this was true. He cautioned that in setting up pollution programs in our own company it is necessary to include the cooling tower blowdown as part of the problem. Technical directors of

* From transcript, 30th Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; Boston, Mass.; Oct. 7–10, 1957.

other plants agreed with Dr. Riley. Therefore, the topic was considered to be of sufficient importance to include on the program.

I think that in any technical discussion we might avoid misunderstanding by trying some definitions, so we will start with Frank Riley. Would you define a cooling tower for the purpose of this discussion?

Dr. F. R. Riley, Staff Consultant, American Cyanamid Co., New York, N. Y.:—For the purpose of this discussion it is our intention to define a cooling tower as a mechanical piece of equipment, usually made primarily of wood, designed to produce intimate contact with a downflowing stream of water and an upflowing stream of air. Not everyone agrees that wood is the most suitable material for a cooling tower and there appear to be strong points in favor of such criticism.

Most of the industrial cooling towers, at the present time, are wood structures containing fans to move a current of air up through the cooling tower, and pumps to lift the water to the top of the tower to supply the downflowing stream of water. This water, cooled in its passage down through the tower, is then circulated with pumps to the cooling system in the industrial plant.

Most of us, who deal with the operation of these towers, usually complain that the operating department finds too many ways to lose water and increase the cost of chemicals for treating these waters. However, such problems are only some of the side issues involved in any industrial processing plant where there are many different types of operations.

Chairman Hedgepeth:—Mr. Garrett, will you define, for the purpose of our discussion, what you mean by regulatory implications?

Jack T. Garrett, Industrial Hygienist, Monsanto Chemical Co., St. Louis, Mo.:—Our main interest, as far as the definition of a regulatory implication is concerned, is the fact that it reminds us that regardless of the source anything discharged from a plant into a receiving stream is under regulation as process waste. This seems odd because it is sometimes hard to get waste treatment people to realize that the blowdown is subject to the same regulation as the process wastes themselves.

If the blowdown from water treatment processes is harmful to the stream then it must be rendered harmless, just as are all the other materials discharged from the plant. In some instances the process can be modified so that the blowdown itself is not harmful to the stream. Whether the blowdown is harmful or not depends to a large extent on what, specifically, is discharged in the blowdown, and its concentration.

This, then, is the regulatory implication. Anything discharged from treatment of water is subject to the same regulation as is any other waste.

Chairman Hedgepeth:—Bill Gibson, from your experience in this field would you help us by defining what you mean by boiler blowdown?

W. E. Gibson, Utilities Engineer, Cosden Petroleum Co., Big Spring, Tex.:—Boiler blowdown is defined as the concentrated water removed from the boiler circulatory system in order to maintain what is used as the basis of concentration control. This water generally has a pH of around 11 and total solids of about 6,000 ppm. These characteristics may vary with the type of boilers operated, the pressure, and the type of boiler feed. The blowdown usually contains some other agents such as anti-foam materials or some type of high-phosphate organic agent. Generally speaking, none of these materials are considered to be toxic.

Chairman Hedgepeth:—We will call on you again to explain what is meant, Frank, by waste waters from industrial water processing.

Dr. Riley:—You can't get something for nothing. That is where the prob-

lem begins in the industrial processing of water for industrial uses. When we treat these various waters—surface waters, well waters, and water from other sources coming into the plant—we usually have a by-product of that treatment process which has different characteristics from water coming into the plant. It is this by-product that sometimes becomes a nuisance as far as discharging it back into the stream is concerned.

Until 10 to 15 years ago, the waste products from water-softening processes to provide boiler feed water were the main constituents to be handled. If zeolite was used, the waste effluent was a solution of calcium or magnesium salts, with the excess sodium chloride used to regenerate the zeolite. If chemical softening was used, the waste effluent was a sludge containing precipitates of calcium, magnesium, and aluminum or iron salts.

Demineralization

In earlier experiences the treatment of industrial water for plant use was primarily for boiler feed. However, during the past few years, particularly in chemical plants, the process requirements for water in some instances exceeded the demand even for high-pressure boilers. The make-up for high-pressure boiler plants is demineralized water. There are three types of demineralizing plants. All demineralizing plants use two different resins.

The first type uses one resin normally regenerated with sulfuric acid, infrequently with hydrochloric acid. The other resin used in this type of demineralizing equipment is usually regenerated with sodium carbonate. An excess of each regenerant is required to regenerate each resin. Thus, the effluent from one of these demineralizing plants at times contains a substantial amount of acid and at other times a substantial amount of sodium carbonate, because the two resins cannot be regenerated simultaneously. There will be more acid than sodium carbonate in the total waste effluent from this type demineralizing plant.

In some instances holding tanks are provided to allow the alkali stream and the acid stream to be mixed together before going to the plant sewer system. In such cases there is an excess of acid.

In the second type demineralizing process, silica removal is required. Acid is again used to regenerate one of the resins, but caustic soda instead of sodium carbonate is used to regenerate the resin which removes the silica. Since silica is difficult to remove from the resin, once it has been picked up from the water, a large excess of sodium hydroxide must be used to regenerate the resin. The total effluent from a silica removal demineralizing plant will usually contain an excess of sodium hydroxide.

The third type of demineralizing plant is the monobed or mixed bed plant. In this type of plant, both resins are usually regenerated simultaneously. The regenerant flows from both resins are mixed. The composition of the mixed stream varies over a wide range during the regeneration period.

In addition to the ion exchange units described, there is often the processing of surface water for use in an industrial plant; it is frequently necessary to remove substantial quantities of dirt from the water with or without simultaneous lime softening. If the characteristics of the water are such that lime softening can be used advantageously with dirt removal, this usually will be done. Effluent from a treating plant of this type is a thin sludge. The chemical characteristics of the sludge are usually not very detrimental. However, the appearance of this small stream of sludge flowing into a stream, and probably not mixing in readily, frequently creates problems because of the old saying that if you can see something you are warned, and

frequently when people are warned it is difficult to allay their fears.

Mr. Gibson mentioned the boiler blowdown which in a way is a by-product waste effluent from water treatment, because actually the operation of a boiler is nothing more than a certain type of water process in which the water is used in vapor rather than liquid form.

Cooling Tower Problems

The primary reason for using cooling towers is the lack of enough water to accomplish cooling by a single use. In the southwestern regions the restricted water supply is more serious than in most areas. In this region there is hardly enough water to provide the make-up of the cooling tower.

In the treatment of cooling tower water for a plant one serious problem is the effect of resulting chemicals on the facilities for waste handling. One of the principal examples of this is the water from cooling towers and heat exchangers.

An industrial water, normally not very corrosive, when used in a cooling tower system and exposed to large quantities of air, may become somewhat corrosive to the heat exchangers in the plant. Also, when this water is recirculated through the cooling towers it is exposed to sunlight and frequently will develop extensive green growth in the top of the cooling towers. Since the green growth will get into the heating equipment and reduce the cooling effect of the heat exchange equipment, a chemical control procedure must be followed.

Slime and Algae Control

As far as slime and algae control is concerned there is not much reason for differentiating between whether the slime is green or black or some other color, or whether it is algae, or what it is. The heat exchanger surfaces must be kept reasonably clean of anything of a slimy nature. A common fallacy at one time was that if a growth was green it was algae but later it was confirmed that it can be green and still not be algae.

Chlorine was one of the first materials used to control slime growth in these recirculating systems and is the most widely used material at the present time. Although chlorine is commonly used, further problems may develop. In such control of certain organisms by chlorine there may arise favorable conditions for some other type of bacteria or fungi that may be just as troublesome as those eliminated with chlorine. This situation has led to the use of more toxic chemicals to control slime and algae. Ordinarily the excess of chlorine required to control algae is not very great and does not create a problem as far as waste effluent is concerned. Since chlorine is considered to be a sterilizing agent, no particular objection was raised ordinarily if chlorine was discharged into a surface stream. However, if various other algicides are used it is necessary for the water treatment engineers to work close in hand with the effluent treatment people to obtain satisfactory results.

Corrosion Control

Since corrosion is one of the principal problems in the reuse of water in a cooling tower system, several different chemicals and methods of process have been developed and successfully used to reduce the corrosive attack on the heating exchangers and other equipment. The amount of these chemicals required to maintain the corrosion attack at a satisfactory level varies considerably. A general method of treatment or a general level of treatment applicable to all water cannot be described because of the variable characteristics of water coming into the cooling tower, and probably to a greater extent in some plants because of the variable materials the recirculating cooling water picks up from the plant atmosphere.

For corrosion control, phosphates, both organic and inorganic, are widely used. Chromates are also commonly used. Sometimes a combination of phosphates and chromates is used. Any of these processes may be modified by the addition of a small amount of some other material to handle the specific conditions encountered in an individual installation. For example, a small amount of zinc may be superimposed to obtain a specific result in a particular installation. In another plant it may be advantageous to add some ferrocyanide. There is quite a wide variety of chemicals used today for treating recirculating waters, and the purpose of this treatment is to maintain the corrosion rate below a definite maximum amount.

The dollar value of the chemicals required to hold the corrosion rate down is rather staggering in some of the plants, particularly in Texas where operations must be at high levels because of the lack of water for make-up of cooling towers. As a result, water is replaced with more chemicals. In some sections of the country where there is an ample supply of water for make-up, operations can be carried on with less chemicals and somewhat more blowdown water to get the necessary corrosion protection.

A common attitude is to ignore the effects of the atmosphere on plant water. However, for eventual control the best thing to do is observe and check very carefully any possible atmospheric effects on recirculating water over a period of time, especially in oil refineries or chemical plants.

Infiltration

There is also the problem of the maintenance of equipment and leakage into some of the circulating water. Sometimes it is possible to detect such leakage by analysis of the water and thus determine the source of leakage. It is not a simple task to pinpoint a leak source.

Preservation of Wood

Finally, there is the problem of wood preservation. This problem is particularly acute in the Gulf Coast region, including Louisiana and Texas. The problem has not been as extensive in the North, although there are wood towers in New Jersey and in the Chicago area where fungus attack has been sufficiently severe to require chemical treatment of the wood after the tower was installed, in order to increase its life. These wood treatments require the use of toxic chemicals and after such treatment there may be a fairly high concentration of these chemicals leaching out of the wood into the recirculating water, and appearing in the blowdown, and finally in the plant waste.

Control of Fungus

Frank W. Anderson, National Petro-Chemicals Corp., Tuscola, Ill.:—Do you recommend approaching the problem of fungus control in cooling towers by the use of fungicides in the circulating water rather than treatment of the wood itself?

Dr. Riley:—There appear to be differences of opinion as to whether the problem is the treatment of wood or the treatment of the water. However, the processes using wood treatment are somewhat older than those using chemical treatment of the water to prevent fungus attack.

Many cooling towers do not show any deterioration due to fungus attack until they are five years old. Some of them may be 15 years old and in good condition yet located next to one that did not last five years. Therefore, there is a time problem which adds to the difficulty of evaluation. A period of three to five years of observation seems to be necessary before any definite conclusions can be made.

It is felt that satisfactory results can be obtained by either process, wood treatment or water treatment.

Wood Treatment

The following experience is cited at a plant where there were two fairly large cooling towers. One of the towers was operated without any particular chemical treatment to prevent fungus attack on the wood. The other tower received periodic fungus prevention treatment. The tower receiving the fungus protection treatment developed a severe attack of fungus whereas the one not treated had a mild fungus attack. Both towers operated with the same make-up water but served different equipment. The operating conditions on both towers were similar; however, the principal difference was that in the case of any leakage into the recirculation system of the tower without treatment the materials were of a toxic nature; whereas, on the tower receiving the treatment any materials that leaked into the recirculation system were nitrogen compounds providing a food supply for the organisms. Such a difference in operating factors may provide an explanation.

The current practice of the American Cyanamid Co., when constructing a cooling tower in the Gulf Coast area, is to treat the wood before installing the tower. Either copper or zinc salts and a chromate is used to form in the wood an insoluble chromate of either copper or zinc, which is toxic to most of the fungus identified as the cause of most of the wood damage. There are preferences both for copper and zinc. Those who prefer zinc look askance at the possibility of copper being released from the wood and causing corrosion in heat exchange equipment. There is some evidence that leaching of zinc from the wood after treatment is at a somewhat lower rate than copper under the same conditions. At the present time the evidence is not conclusive whether there is much reason to choose between a zinc or copper salt with chromate. Work is continually in progress to develop processes to control fungus in wood, but at the present time complete success has not been attained.

Some of the treated towers have been in operation for four or five years. Some were treated after the fungus attacked the wood and the fungus growth was arrested. In those observations it was indicated that the wood had deteriorated very little if any. In evaluating the life of the wood treatment American Cyanamid Co. arbitrarily picked a time of three years as the expected life of the treatment.

Costs

In the comparison of costs for wood treatment vs. water treatment there is some evidence to support the belief that wood treatment is somewhat more economical than water treatment. This belief is based on the assumptions that water treatment is satisfactory and that wood treatment is effective for at least two years.

Chemical Treatment of Water

There is a wide range of chemicals recommended for treating the water. Economical comparisons can be confusing, depending on whether minimum or maximum treatment is considered. Those having the most experience in treating the water usually recommend the greatest amount of chemicals.

Mr. Anderson:—It appears that when water is treated it becomes a waste problem; whereas, if wood is treated it becomes a problem only for three years.

From the Floor:—What do you add to the water?

Mr. Anderson:—Quite a few materials are added, chlorinated phenol being one that is widely used.

Chairman Hedgepeth:—May I elaborate concerning the question of the nature of the chemicals added to the water to control this fungus or microbial attack? I think the technical idea is that fungus may be a too narrow definition. I don't believe we have established that this attack is from

fungi. It is some form of microbial life. Mr. Anderson mentioned the use of chlorinated phenol. It seems to me that in one plant I had a first-class headache from sodium phenate.

Dr. Riley:—Sodium phenates are probably the most widely used compounds, although there are several other organic and inorganic compounds used in specific cases. Generally speaking, these other compounds have been developed because of the waste effluent problem created by the use of pentaphenols, particularly chlorinated phenol. The recommended quantity of other chemicals required to do the same job as chlorinated phenol is usually substantially greater; however, it is difficult to keep abreast of constantly changing developments that may produce changes at any time.

Again the factor of three to five years for evaluation of the problem appears desirable based on the number of cooling towers in the Gulf Coast area where there was no attack for many years.

Vincent D. Lukas, General Electric Co., Schenectady, N. Y.:—May I supplement the introductory paper with a few comments? Most people realize we are speaking of cooling water. We have to remove the heat from the processes in industry; therefore, we must look for some efficient mechanism to do this. This morning we are talking of cooling towers; however, we could also be talking of evaporative condensers and cooling ponds.

The cooling tower is a very efficient mechanism. For every pound of water evaporated we gain 1,000 Btu. Another way of saying this is, if we want to cool 100 lb of water 10° F we are going to lose one per cent of the water in evaporation.

In this discussion we have been talking of corrosion treatment and algae treatment. Obviously if we do not control the solids in the cooling tower there will be scale. The loss of 1 per cent is not sufficient to keep down the solids. As a result, blowdown must be a factor in cooling water treatment and that is where we get into the problem of polluting the streams.

Don E. Bloodgood, Professor of Sanitary Engineering, Purdue University, Lafayette, Ind.:—I was going to ask if chlorinated phenols in discharge would be detected by the use of tests recommended in this discussion for the detection of phenols.

Mr. Garrett:—Generally, the material used must be soluble and most phenols are insoluble. Therefore, if the salts of the phenols themselves, sodium and others, are used, then the salt would be detected, but when considering fully chlorinated material I do not think the phenols are detected. Pentachlorophenol, which is one of the most commonly used, is not detected with this test. Some have indicated the use of the 4-aminoantipyrine test in connection with pentachlorophenol.

Walter E. Williams, Sanitary Engineer, Naugatuck Chemical Div., U. S. Rubber Co., Naugatuck, Conn.:—I wonder why, with all the investment involved, both a water treatment system and a wood treatment system would not seriously be considered. Our company manufactures a fungicide and algicide, designed for minimum stream pollution, active in very low concentrations, and I am certain that there are other types of material that we should start investigating. It is my feeling that perhaps we have been too complacent the last 10 or 15 years in the solution to our problems.

Dr. Riley:—I think there are many who are hopeful that some of the methods now being recommended for water treatment will prove equally feasible for these controls. We are also hopeful that someone will develop a material that can be used at a lower concentration and does not cause disturbances in waste effluent treatment.

I feel there is a good chance for success if we treat the wood to start with and also treat the water that has passed

over that wood. We then have a much better chance of preventing wood deterioration than if we rely on only one of the processes, since with the large volume of water that passes through a wood tower a material may be only slightly soluble and yet be susceptible to leaching. Therefore, it seems doubtful that enough chemical can be placed initially in the wood to protect it indefinitely. However, some type of wood treatment should be effective in retarding the leaching.

M. B. Ettinger, USPHS, Cincinnati, Ohio:—First, I want to take issue on the discussion of the detection of phenol by the 4-aminoantipyrine method. I am positive that it will not detect the pentachlorophenol. If there is a response to trichlorophenol it is minimal, although a check of data would clarify the point. The use of this method probably makes it easy to get a zero phenol indication in an effluent. On the other hand, phenols require somewhat different consideration than many materials when abatement of stream pollution is discussed.

Then there is one other comment I want to interject. We apparently have no biologists present. If there were, I believe these gentlemen would be inclined to think that you were doing an important service by using cooling towers. The biologist takes the view that a rise in temperature in a stream can definitely degrade the quality of the water. One example often cited concerns the trout stream in which the temperature is raised 10 or 20°F and the trout then disappear.

Chairman Hedgepeth:—I think the panel will agree with your position on this. Let me say that this oblique question that came from Professor Bloodgood, and was received with smiles from the panel members and others, is one being considered extensively within the limits of the two water pollution abatement committees serving the chemical industry.

Mr. Garrett has been a proponent of having the excellent 4-aminoantipyrine method used only for what it is intended and not as a method of taste and odor detection and measurement. He is quite right in that. But we have no good method available now for accurately stating the taste and odor problem of water. The only one authorized by the Tenth Edition of "Standard Methods" is based on human smell which at best is only one-third valid and that perceptive sense tires very quickly. It is nothing more than a rough assay method.

Mr. Williams:—I have a question on stream pollution. Has any consideration been given to holding the last portion of the wastes from demineralization units for the first wash of the ion exchange material after the next cycle?

Chairman Hedgepeth:—We follow that practice at American Cyanamid. It is the practice to hold these wastes and let them neutralize. I believe that as a final result it is common to have some excess caustic.

Hayse H. Black, Sanitary Engineer, USPHS, Cincinnati, Ohio:—There are various types of cooling towers and there is one that has a very definite bearing in connection with stream pollution. With your permission I would like to mention the gas coolers in a coke plant. In this instance most of the gas is cooled by direct contact with water. The water coming in contact with the gas picks up cyanogen compounds and many other compounds we do not know much about; but we do know that this water is some of the most toxic we have ever studied in its effect on fish. Some of this water is occasionally spilled into the stream if there is a sewer in the area. It is a fact in some cases, one case in particular, where the cooling tower was too small and was shut down while another was being constructed, and this cooling water discharged into a very large stream and killed tons of fish. Therefore this is one type in which there is keen interest.

Chairman Hedgepeth:—That is one reason we thought this topic was timely. It has not been generally recognized to be much of a problem.

In summation of the first part of the discussion I think we have said that in the evaporation of water the cooling tower absorbs heat and through the discharge of water vapor there is a concentration effect; therefore, the mineral concentration of the water builds up and necessitates occasional blowdown to keep these minerals within desired limits. No one has as yet inquired what these limits are. I think the panel is ready to discuss this subject.

In the cooling process there occurs microbial growth, including slime and fungus, which physically impedes the flow of water and interferes with the function of the recirculating water through the heat exchange equipment in the plant. These growths also break off and cause pollution in the blowdown. They must be arrested and kept under control, and to do this we use algicides which are often toxic in nature.

Dr. Riley pointed out that the nature of the cooling tower was such that the water was saturated with dissoluble oxygen and carbon dioxide, and the chemical characteristics are altered by treatment, thus creating corrosive characteristics. Therefore, corrosion inhibitors must be added to prevent attack to the manufacturing equipment. These materials introduce other toxic elements, such as chromates, zinc, copper, etc., all of stream pollution significance.

Finally, a new phase of the problem has been developed in this discussion—that of the microbial attack on the wood of the tower itself. More recently it has been shown, and generally accepted today, that the factor is not due to chemical nature or phenomena but a microbial attack, and I believe it has been developed that we have found no satisfactory method of arresting it completely. We recommend treatment of the wood of the tower when placed in service as well as treatment during the operation. The tower that Dr. Riley indicated has given no trouble, I believe, is one located near a hydrocyanic acid plant.

Regulatory Implications

Chairman Hedgepeth:—We have seen that in order to keep the cooling tower operating it is necessary to use a variety of additives. In the discharge to the stream there may be solids concentrations of 1,000 or more ppm.

We now call on Mr. Garrett to discuss the regulatory implications of this discharge.

Mr. Garrett:—This subject covers a multitude of sins but can be boiled down to mean one thing. If the effluent from the water treatment process contains anything harmful to the stream then there will be trouble unless something is done to correct the situation.

Background

It is necessary to consider what is being done and what is being discharged. For example, there are three main classes of materials used in the process of treating water. These would be of interest to the industrial wastes people who have the responsibility of treating any harmful material that is discharged by this process, and also to the regulatory groups who deal with the approval of a plant's waste discharges which include the wastes from this process.

First there are the usual inorganic materials coming from pH control, demineralization, scale prevention, etc. Next there is the process of corrosion control which adds certain chemicals to the blowdown water and subsequently to the effluent. Third, there are disinfectant chemicals (an all-inclusive term to cover all the microbial and algae materials for all types of living organism control—slimes, fungus, etc.).

pH, Demineralization, and Sanitation

In discussing these three classes of materials it can be said that in general the materials used in pH control and scale control do not necessarily affect the effluent quality. The required pH control is generally between the range of 6 to 7.5 or 8. Frequently, sulfuric acid is used for this purpose because of the benefits obtained from the sulfate ion in scale prevention. As to the use of descaling material, pH control and hardness control are in themselves prevention of scaling, but in some cases certain agents are used to remove metals or other materials that will cause scale. Most of these latter materials are used in such minute concentrations that they are not particularly harmful.

When large demineralizing systems are considered, particularly in some of the multibed units, damage to the receiving stream may result from the amounts of acid or alkali discharged. The pH change in the receiving stream due to these discharges may cause damage to aquatic life and fish since such environmental changes affect the aquatic food supply. Such effects will quickly bring the industry under the scrutiny of the local fish and game authorities.

Corrosion Control

As a general statement it may be said that most of the metallic substances used for corrosion control are rather toxic. They are generally heavy metallic salts and in most cases quite toxic to fish. The chromates, zinc salts, the ferrocyanides, or their end products resulting from chemical change in the process, are examples of these toxic materials. With some of these toxic metals it is first necessary to determine what their concentration is in the final dilution. A second requirement is to determine, with a fair degree of accuracy, the biological environment in the receiving stream and what effect this material might have. The effect on fresh-water organisms of most of these metallic salts is reported in the literature. For example, there are many references on effects of chromates to fresh-water fish of all types and even the effects on marine organisms. It is frequently assumed that the effects of a certain material are easily recognized, but there are occasions when some unpredicted bizarre effect occurs in the receiving stream. For example, the fatal effect of chromium on fresh- and salt-water catfish is unusual when you consider that these species are among the hardiest known. Yet the apparent weakness of these species toward chromium perplexed industry and the regulatory agencies for many years.

Zinc, as a matter of fact, is more toxic to fish than chromium. Whether a substance is toxic or not depends not only on what it is but how much there is, of course. If in the blowdown of a water treatment process there are 50-ppm chromium residual normally, trouble will not occur unless the discharge is into a small stream. In addition to the chromium and zinc salts there are the ferrocyanides. The toxicity of these compounds depends principally on the cationic species and the possibility of degradation. In most cases, however, toxicity information is contained in the literature and the effect of the blowdown can be estimated by determining final effluent concentrations.

Sanitation Control

Under the classification of sanitation materials there are additives to control algae, fungus, and anything that appears to be causing growth and interfering with the heat transfer process itself or degrading the wood or any of the other process equipment. As has been stated in the use of algicides, the principal material is chlorine or one of the chlorine-producing compounds. In addition some of the phenol compounds, such as copper

phenates and zinc phenates, are used for this purpose. Frequently combinations of chlorine and phenates are used for a single dosage to control the over-all growth. It is the general belief of some people that such treatment will control all growth in the average cooling tower. It is not proposed to argue whether it is better to treat the wood before or after it is erected. From timbers pressure-treated with creosote or otherwise treated with copper there will be some leaching, which in addition to other toxicity problems might enhance the over-all toxicity of the waste stream. Copper compounds are extremely toxic to fish and other aquatic or marine organisms. Sodium pentachlorophenate has a toxicity in the order of 0.25 ppm. The control of these materials in the receiving stream must be carefully maintained and a knowledge of the downstream geography as well as uses must be kept in mind. For example, if there is a dam downstream from the discharge it could cause this material to become stagnant and build up to toxic levels. Fortunately, the pentachlorophenates undergo bacteriological attack in the stream with the same efficiency as the parent phenol itself, thus preventing major build-ups.

Summary

In most instances of an individual cooling tower or an individual treatment system the problem is based to a large extent on the characteristics of the incoming water because this tends to dictate the type and concentrations of additive materials. The raw-water quality also influences the blowdown rate. The raw-water quality, therefore, influences the ultimate pollutional potential of the discharge. It might be deduced from this that one method of pollution control would be careful selection of the raw-water supply if, indeed, any selection is possible.

The best way to approach the problem of cooling tower discharge toxicity is to examine the receiving stream and determine what processes will produce an acceptable water and a non-toxic effluent. This is not nearly as difficult as it appears, since most of these treatment chemicals are discharged in very minute quantities. However, if this is not possible then other treatment to remove the offending material is presumed and this is a difficult task.

George A. Rhame, Sanitary Engineer, Division of Water Pollution Control, South Carolina State Board of Health, Columbia, S.C.:—In regard to the difficulty of detecting some of these chemical compounds in water I remember that somebody reported that they had been able to detect certain compounds by the movement of fish in an aquarium through which the suspected water was flowing. I just wondered if the Public Health Service in Cincinnati has anything to offer about this or any other method, such as using dogs to detect chlorine in water.

Mr. Ettinger:—I think that bringing dogs in is somewhat a moot issue. It is generally accepted that the bloodhound is a court-worthy animal but it is difficult to get a bloodhound to come to court to testify on whether the odor of water is repulsive to a human.

As to the other question, the study of evasion of toxic material by fishes is going on to a degree by some of our biologists but I do not know enough of their work to give a report.

Chairman Hedgepeth:—In looking over Professor Renn's studies in toxicity and various solutions used on live fish, I do know that fish that school together tend to become antisocial when pollution is present. However, they become excitable before the harm occurs.

Harry A. Faber, U. S. Public Service, Washington, D. C.:—I heard the comment on bloodhounds. As in all scientific work I think we are going to get more complex problems. There is at present a research grant from the

Public Health Service to a biologist who is studying cholesterin activity of fish brain tissues. The work is being done by Dr. Weiss at the University of North Carolina. We may be forced into such complex methods to bring us evidence, rather than bloodhounds, as to the concentration and the degree of activity of some of these toxic materials in the water.

Mr. Garrett:—As I understand it, the work being done by Dr. Weiss is based on leaching into the water of phosphate insecticides, which are very common neurotoxins, and their effects on the nervous system of fish.

There has been a great amount of research in recent years on very small aquatic animals based on the possibility of interrupting the food cycle of the aquatic life and resulting effects on aquatic population. The work done by Dr. Weiss is extremely complicated and would appear to me to be quite a task to apply on a practical basis.

Chairman Hedgepeth:—I would like to point out that an industrial wastes man is on dangerous ground if he does not take into account biological testing. As an example, recently we were assessing the stream pollution potential of an entirely new plant with a new process and new chemicals. Only by accident during the biological assay did we find that certain of the sludges that precipitated under some conditions were highly toxic to fish while the effluent was not. This observation was made when the observer noted that on stirring the test aquarium with his thermometer to get a good reading the fish got excited. In the final arrangements this fact has been taken into very careful account.

We talked a great deal about the wooden cooling tower and someone asked if we were moving to some other method of getting rid of this excess heat in our plant rather than the cooling tower with its attendant complications. I will call on Mr. Gibson to tell us about a very unique solution that they have arrived at in their company.

Mr. Gibson:—In the way of background, the refinery referred to is at Big Spring, Texas. At this plant there is processed 30,000 bbl of crude oil a day, of which 20,000 bbl are sour West Texas crude oil, and 10,000 bbl are sweet Benedium crude oil. At this plant there is the usual fluid catalytic cracking unit, thermal cracking unit, H. F. alkylation unit, polymerization unit, platformer and udex unit, rexformer unit, and styrene monomer unit. Actually the last unit is the only one that falls outside the routine refinery unit.

This refinery is located approximately 250 miles west of Fort Worth. For those of you who do not know the area it is in the middle of an arid part of the country. If there are 12 in. of rain a year it is lucky. The evaporation rate is 72 in. a year. Therefore, it is advantageous for getting rid of waste.

Actually, water in this part of the country is more valuable than capital investment because it is a prime necessity in order to operate.

Evaporative Equipment

At this plant the solution to the cooling tower blowdown is maximum utilization of air-cooled and evaporative type equipment. Air-cooled equipment is installed and uses a fan by forced draft or induced draft over finned tubes, and uses air as the heat exchange material instead of water. There are obvious limitations to this type of cooling and in order to overcome those obvious limitations use is made of what is called the evaporative type air-cooling. This is a cross-flow cooling tower with a finned tube heat exchange element set beneath the fan. In that way air is pulled through the water and completely saturated with water before passing over the tubes.

This equipment has been used to reduce the amount of water consumed in the plant and to increase the capacity of the unit without increasing the heat load of the system. The first air-

cooled equipment was installed in 1951 and that proved to be so satisfactory that a policy has been adopted of using that equipment wherever possible and in all new units constructed since that time. In addition, there is a program under way to replace, in every location possible, existing cooling equipment with air-cooled equipment. This refers primarily to submerged cooling coils, which are a very inefficient method of heat exchange. In some cases cooling vapor streams with air coolers is done and then a shell and tube heat exchanger is used for after cooling.

This program has resulted in the air-cooling equipment on all except two process units, the polymerization unit and the alkylation unit. New units designed to use maximum air-cooling have been the platformer and udex unit, rexformer unit, and styrene monomer unit. When consideration was given to a new unit in 1955—the rexformer unit—a study was made of the amount of cooling water involved. Actually, the engineering contractor concluded that there would be needed something like 6,000 gpm of water with a 30°F temperature rise in order to remove the heat from this unit. By going back and redesigning the cooling equipment to utilize maximum air-cooling and evaporative type cooling it was possible to reduce the requirement to 1,600 gpm with a 12° F temperature rise. Actually, 90 per cent of the heat load is removed by air-cooling. In another more recently completed unit, 77 per cent of the heat load is removed. These are but two of the examples of the application of this equipment to reduce the circulating water requirement.

Blowdown Reduction

Obviously, by reducing the size of the circulating system the amount of cooling tower blowdown is reduced. In the first case above, the theoretical blowdown rate, based on 10 concentrations, is reduced from 28,800 gpd to 2,016 gpd. Since there is used a chromate corrosion inhibitor of 135 ppm, this blowdown reduction removes 30 lb of chromate a day from the waste stream.

Some clarification is desirable concerning the statement that it is possible to attain 10 concentrations. Actually, due to some of the things pointed out earlier by Dr. Riley, that point is not reached. Improvements are being made and are leading toward this objective. From this point alone it is easy to see what can be accomplished by way of cooling tower blowdown reduction if a complete refinery could be designed to utilize the equipment. Approximately 50 per cent of the heat load in the refinery is removed by air-cooled equipment, and the total load is something like 500 million Btu per hour in all the refinery units.

Actually, the refinery cited here does not represent a pioneer in the field of using air-cooled equipment. Practically every plant in West Texas and New Mexico uses a good deal of this equipment and there are many such installations along the West Coast.

Cost

It is relatively simple to control the operating pressure on air-cooled equipment by equipping the fans with variable pitched blades. With such an installation there is effected quite a saving in operating cost.

The problem of capital investment for air-cooled equipment has been analyzed and it appears that the cost is approximately $3,000 per million Btu of cooling capacity. Operating costs are approximately the same as for conventional systems.

Advantages of Air-Cooling

In addition it is permissible to install this air-cooled equipment adjacent to the processing unit, even evaporative equipment, because there is no water spray or carry-over, since the air, even if saturated with water vapor, after

it passes over the hot cooling section is unsaturated with vapor due to the increased temperature. There are no long lines to run to the cooling tower and no pumps to operate. It is now common to install straight air-cooled units in some of the heavy oil streams where it is possible to discharge an effluent having a temperature of 150 to 180°F.

The evaporative type air-cooled equipment, further, has the advantage of being able to take a portion or all of this water and circulate through the conventional shell and tube type of equipment before being sent back over the tower to cool the air. In two installations cited herein water is circulated through the shell and tube equipment; therefore, there is not a separate water-cooling system.

It appears that the difficulties of the wooden cooling tower and the water shortage in the southwestern part of the country can be coped with by using air-type cooling equipment. If an evaporative type of equipment is used where it is not necessary to circulate that water through shell and tube equipment, it is possible to use almost any quality of water. Of course, the concentration must be checked but there are many advantages to be gained. For example, in one unit a condensate pretty heavily saturated with hydrocarbons is being used.

Chairman Hedgepeth:—Bill, is it true that you ran your plant for several years on nothing but sewage because you were so short of water?

Mr. Gibson:—That is correct. It was a little bit before my time but I believe we were pioneers in using sewage and disposal effluent from a municipality. This procedure started in 1943 and it consisted of our total source of water until 1956. In 1956 there was made available to us a large quantity of surface lake water which we have been utilizing in our cooling system. Actually we have continued to use, and still are using, sewage disposal plant effluent after treatment, of course, in our boilers. It appears to be quite satisfactory.

Chairman Hedgepeth:— Well, I judge then that the essence of your solution is to eliminate the wooden structures that are biologically vulnerable, substitute metal structures, and take the bulk of your heat transfer load by air and precool that air with water vapor. I don't believe you told us of the material recommended for the structures.

Mr. Gibson:—The air coolers themselves are standard materials while the tubes in our heat exchangers are the Wolvertan type tubes. The tube materials might be steel or some of the higher alloys of steel or low chrome alloys. Extruded over that is an aluminum tube with half-inch high aluminum fencing spaced about a quarter of an inch apart. This provides, in effect, an extended surface and increases the rate of heat exchange. The underpinning or support structure is made of standard steel structure members.

In the evaporative type we have wooden cooling towers. Both units are of redwood construction. We would like to get away from that if we could come up with something better. It appears at the present time that one of the best chances in the future to get away from wood completely would be to utilize plastic material. I hope to see it some day soon.

Mr. Rhame:—This idea of using the sewage in the plant is very interesting. However, as I am also on the State Board of Health, I am interested in the question of whether you have to take any special sanitary precautions with that sewage. The idea of so much sewage circulating around in the plant where there are so many people intrigues me.

Mr. Gibson:—We use no special health precautions to protect the workers. Perhaps I should carry

that a little further and explain the type of treatment we give the water. The treatment is purely for hardness reduction to make it suitable for boiler make-up. Of course, in doing that we use a hot process softener. We are actually feeding lime and gypsum at the present time and having very good success. We can reduce the hardness to approximately 10 to 12 ppm. Then we use a hot phosphate after-treater which may not be the most economical way to do it but we happen to have the equipment. There we can reduce the hardness even more. Then we filter it. The next step is through a deaerator, from there into a blanketed storage tank, and finally into the boilers. Actually, we are operating low pressure boilers (175 psi operating pressure). Therefore, it is not a severe service at all.

Chairman Hedgepeth:—Your answer, with respect to the question, is that the nature of your processing for the use of water carries its own protection.

William S. Wise, Director, State Water Resources Commission, Hartford, Conn.:—Those of us in regulatory agency positions naturally are gratified to hear of any new processes that have any effect on pollution abatement. Maybe I wasn't too alert to Mr. Gibson's remark but because there is so much of the heat removed by air and so little by water why is it not possible to eliminate completely the water cooling part, or are there some limitations of the use of these air coolers requiring water supplements?

Mr. Gibson:—Unfortunately, in the industries discussed here, temperatures are very important in the effluent streams. You can understand that in a gasoline stream it is necessary to have a stream temperature down around 100°F or there will be a high loss due to vaporization of the material. Therefore, the primary objective in the straight air-cooling is to remove the heat of vaporization in the material. This is where the big heat load is. By using the evaporative type process discussed it is possible to cool the effluent stream to within 20° F above the water temperature which is adequate in the manufacturing process.

The plant under discussion was built in 1929 and there is still one original unit operating. Therefore, modernization is not complete, but as economics permit, air-cooled and evaporative type equipment is being installed as replacements. It does not appear that it will be economically feasible to eliminate completely all the cooling water. However, if a new refinery were to be built from the ground up it is estimated that the present ratio of 50 per cent of the load cooled by air could be increased to 90 per cent easily.

Chairman Hedgepeth:—I think there is a danger of misunderstanding here. When Mr. Gibson speaks of effluent stream he does not mean it as we understand it in stream pollution work, but the effluent stream flowing from his plant.

John Drollet, Phoenix, Ariz.:—In Las Vegas the effluent from a sewage treatment plant is used in the cooling tower for the power plant. This is necessary to operate the power plant. It is completely treated sewage and then, of course, chlorination keeps the cooling tower free of algae. There are only eight people involved in the steam plant and they are not exposed except for one man in the cooling tower. The sewage is variable in concentration and the problem is getting rid of the effluent from the steam plant, because that goes back into Lake Meade.

James N. Miller, Process Engineer, Gulf Oil Corporation, Pittsburgh, Pa.:—Mr. Gibson, would you mind repeating your comment on the capital investment?

Mr. Gibson:—The economic evaluation of this equipment has been on the basis of new construction; in other words, a complete new unit from the

ground up. In the unit where there is a transfer of approximately 90 per cent of the heat load by air, the investment cost was about $3,000 per million Btu per hour of cooling capacity. The investment cost and operating cost for this type of equipment is at least comparable to the operating cost of conventional cooling equipment. This is at least comparable because, naturally, the biggest problem is in the summer when temperatures of 100 to 105° F, day after day, lower the effectiveness of heat exchange equipment. In the winter it is possible to shut down many of the fans, either partially or completely, using a two-speed arrangement on the low speed. Naturally, this procedure would reduce the operating cost.

On the evaporative type equipment all of the water circulation would be shut down in the winter and the equipment could be used as a straight air-cooled unit, except that approximately half of the water in shells and tube exchangers is circulated and must be recooled again under any circumstances.

Therefore, the operating cost at worst is equivalent to the standard circulating system and at best has an economic advantage.

In connection with the use of sewage effluent, regardless of how it is treated, the degree of treatment must be quite high, primarily for the phosphate reduction. It is necessary to have a pH between 10 and 11 before it is possible to get that reduction in the equipment. This problem is not present in the hot process equipment. This operation is around 240°F and the phosphate reduction is accomplished without the introduction of an excess of chemicals.

RUSSIAN TECHNICAL TRANSLATIONS

One of the engineering member societies, the American Society of Mechanical Engineers, has announced that a leading Russian technical journal will soon be translated into English on a regular basis.

Under a grant of $35,000 from the National Science Foundation, ASME will publish the bi-monthly "Journal of Applied Mathematics and Mechanics," known in Russian as "Prikladnaya Matematika i Mekhanika," usually abbreviated as "PMM."

This is to be undertaken in an attempt to correct the present situation wherein the Russians are familiar with the content of most, if not all, of the western technical publications, while only a few of theirs are translated for use by the English-speaking world.

Perhaps this action will show the way for other technical organizations to widen the scope of source information to the English-speaking world. The recent events in space have pointed up the fact that in technical fields there are no natural boundaries between nations.

AERATION OF WHEY WASTES. I. NITROGEN SUPPLEMENTATION AND SLUDGE OXIDATION *

By Lenore Jasewicz and Nandor Porges

Eastern Regional Research Laboratory,† Philadelphia, Pa.

Treatment of whey wastes is generally considered a difficult problem, as evidenced by the fact that some 79 per cent of cheese plants have waste disposal problems (1). This is as true for small plants receiving less than 75,000 lb of milk daily as for larger installations. The magnitude of the problem was also indicated by Sanders (2) in 1947 when he estimated that 5,000 producers of cheese in the United States do not treat their wastes.

Some practical method of pretreatment of cheese factory wastes before discharge into small municipal sewer systems was recommended by Backmeyer (3). He cited the adverse effect of whey on an activated sludge plant even though the whey increased the daily BOD loading by only 11 per cent. According to Johnson (4) conventional sewage treatment processes adapted to cheese wastes are prohibitive in cost for the small cheese plant. Waste treatment must also be simple in operation and as nearly foolproof as possible. Bloodgood in 1948 (5) listed requirements for a satisfactory treatment plant and stated that it will take time and effort to accomplish the desired service.

Waste waters from cheese factories not treating whey wastes vary in BOD from about 700 to 5,000 ppm. At one time it was believed that the only practical method of getting rid of whey wastes would be anaerobic treatment (6), although such plants are not presently known to the authors. Lately, spray irrigation of whey has been reported to be successful in certain localities (7) and in this connection the Eastern Regional Research Laboratory has a contract study underway at the University of Wisconsin to determine under which conditions whey waste can be sprayed. Many cheese factories, however, are unable to dispose of waste waters directly on land and must resort to other disposal methods.

This report covers the successful treatment of whey wastes in the laboratory by biochemical oxidation. The techniques employed were those used in previous dairy wastes investigations (8)(9)(10)(11). Studies were made at different times on the same aerating sludge used for a period of 96 days in daily whey waste treatments.

Experimental

The aerobic fermentors extensively used in the authors' previous work on dairy wastes again constituted the laboratory waste disposal units. An aerator-stirrer mechanism provided thorough aeration and agitation of 12 l of sludge-waste mixture in a glass jar. The temperature was maintained at 29 to 31°C by means of a controlled-temperature water bath. Excess air was supplied at the rate of 1½ volumes (18 l) per minute.

The sludge was propagated from an active aerobic culture obtained from an industrial dairy waste disposal unit.

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† A laboratory of the Eastern Utilization Research and Development Division, Agricultural Research Service, U. S. Department of Agriculture.

Daily additions of skim milk solids were made to the settled sludge after siphoning off the supernatant liquid. After 30 days of this treatment, the seed sludge was prepared by dispersing the cell solids with tap water. The supernatant wash water was drawn off and the settled sludge was distributed into each of two aerators to give a final concentration of 2,000 ppm sludge solids in 12 l.

The experiments were conducted so that 4 l of seed were retained in each aerator. To this, 8 l of solution containing 12 g dried whey were added in a one-dose feeding. Agitation and aeration were halted during the few moments of feeding. Values for zero starting time were obtained on samples of seed sludge and calculated for the starting volume of 12 l. Prior to sampling, adhering sludge solids were carefully brushed from the sides and bottom of the fermentor and dispersed throughout the solution. Water was added to the 12-l mark to replace evaporation losses. The mixture was agitated while the sample was removed by a siphon.

The experimental work was designed to study the rate of whey removal from solution as affected by nitrogen supplementation. Studies initiated on March 5 provided for two fermentations of mixed liquor composed of 2,000 ppm sludge and 1,000 ppm whey determined by the rapid COD test. A daily schedule of 12-g whey-solids (1,000 ppm) additions following effluent removal was maintained. The addition of 175 mg nitrogen as ammonium hydroxide to one fermentor gave a COD : N ratio of 30 : 1, as compared to 50 : 1 in unsupplemented whey.

On the 1st, 21st, and 96th days after whey feeding commenced, a schedule of analyses was followed to ascertain whether the supplemented and unsupplemented sludges were retaining their whey purifying abilities. Samples were removed ½, 2, 3, 4, 24, 48, and 72 hr after whey had been introduced. The total sludge-mixed liquor was assayed for COD, suspended solids, and nitrogen. Suspended solids were determined by filtering 25-ml samples through tared asbestos mats on Gooch crucibles. The filtrates obtained were examined for COD and Kjeldahl nitrogen.

Whey Removal or Purification

Rates of whey removal in the three sampling periods were high. A sludge propagated on skim milk and one acclimatized to whey for several weeks removed more than 90 per cent of whey COD in 30 min, regardless of nitrogen additions. Within 2 hr the solutions were practically clear of soluble material as determined on the Gooch crucible filtrates. This points out the practicability of removing the clear effluent soon after feeding, as suggested by Kountz (12) and Eckenfelder (13).

In the first series, an average of 2,072 ppm sludge solids was used with 1,000 ppm whey. For proper sludge activity 7 per cent N is considered the minimum content required in a mixed liquor according to Helmers *et al.* (14). Therefore, 215 ppm nitrogen should be present. The empirical formula for sludge (8) shows that 124 units contain 14 units of nitrogen; hence the 2,072 ppm sludge should contain 234 ppm N. This plus 19 ppm introduced with the whey is more than sufficient to meet nitrogen requirements.

Table I presents changes in the COD of the suspended solids. The maximum increase was reached in approximately 30 min. Thereafter, steady decreases in the COD of the solids were observed. In general, not quite all the added whey COD was oxidized in 24 hr of aeration. Slight but noticeable increases in sludge concentration occurred.

Table II summarizes COD data on the amount of whey removed from solution, increases in suspended solids, and, by difference, the amounts of whey actually oxidized. Here, the rapidity and completeness of whey removal are again observed. This capacity of sludge to

TABLE I.—COD Changes in Suspended Solids of Whey-Fed Sludge With and Without Added Nitrogen

Time After Whey Feeding (hr)	COD Changes (ppm)					
	Whey Fed*					
	1st Day		21st Day		96th Day	
	No N	N	No N	N	No N	N
0†	2,567	2,337	4,810	4,794	4,952	4,952
½	3,494	2,942	5,492	5,343	6,059	6,084
2	3,388	2,570	5,469	5,222	5,722	5,969
3	3,069	2,561	5,401	5,133	5,672	5,537
4	2,763	2,525	5,328	5,213	5,597	5,567
24	2,628	2,525	4,678	4,718	5,462	5,280

* 1,018 ppm whey COD.
† Before feeding.

store and assimilate nutrients had been demonstrated by Gellman and Heukelekian (15) and others (10). The storage product is a glycogen-like material and may approach one-third of the total cell weight (11). As this stored material is converted and oxidized for cell energy, the sludge solids gradually diminish.

The milk sludges exhibited the best ability to oxidize whey, showing 82 per cent oxidation in 4 hr. As the sludge was fed whey this oxidizing ability was slowly weakened, until by 96 days only 36 per cent could be oxidized in 4 hr. Added nitrogen was of some help; 67 per cent oxidation occurred, as compared to 50 per cent in 24 hr with the unsupplemented 96-day sludge. Although the older whey cultures are able to purify whey solutions quite readily, their impaired oxidizing ability would result in marked sludge build-up. The greater rate of oxidation by the milk-fed sludge may be attributed to the presence of substances in milk conducive to the rapid oxidation of whey.

Sludge Stabilization by Oxidation

Changes in suspended solids were followed over a period of 72 hr from the time of whey addition. Figure 1 shows the stabilization of a skim milk sludge used for whey purification. Although the removal of whey from solution was not accelerated by nitrogen addition (Table II), ammonia did favor oxidation of suspended solids and hence stabilization of the sludge. This unacclimatized milk sludge was oxidized back to its starting weight of 2,064 ppm within 16 hr. The comparable unsupplemented sludge required 60 hr.

The 96-day whey-acclimatized sludge

TABLE II.—Whey Removal, Whey Oxidized, and Suspended Solids Increase of Whey-Fed Sludge (as ppm COD)

Time After Whey Feeding (hr)	Unsupplemented			N-Supplemented		
	Whey Removed	Susp. Solids Increase	Whey Oxidized	Whey Removed	Susp. Solids Increase	Whey Oxidized
			(*a*) 1st Day			
½	907	927	—	935	605	330
2	1,018	921	197	1,018	233	785
3	1,018	502	516	1,018	224	794
4	1,018	196	822	1,018	288	830
24	1,018	61	957	1,018	288	830
			(*b*) 96th Day			
½	930	1,107	—	955	1,132	—
2	1,018	770	248	977	1,017	—
3	1,018	720	298	961	585	376
4	1,018	645	373	966	615	351
24	1,018	510	508	1,018	318	700

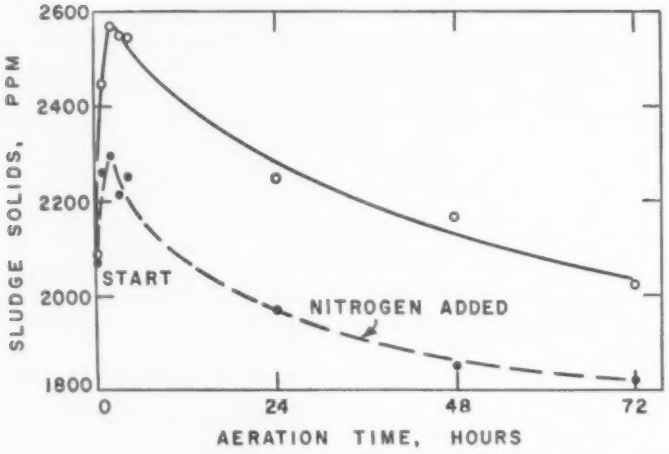

FIGURE 1.—Changes in sludge concentration during continuous aeration following whey addition (sludge cultivated in skim milk).

exhibited similar trends. Approximately 26 hr were needed for the NH_4OH-whey-fed sludge to return to its original weight, as compared to 60 hr for unsupplemented whey sludge (Figure 2).

Figure 3 shows the percentage of suspended solids oxidized by the milk and acclimatized sludges. These values are based on the sludge weights 2 hr after feeding. By 70 hr, the percentage of sludge oxidized was about the same whether nitrogen-supplemented or not. Sludge oxidation reached 15 per cent within 24 hr in these tests, as compared to 23 per cent previously reported for dairy sludges (11), 23 per cent for pharmaceutical, 10 per cent for sewage, and 7 per cent for paper and pulp sludges (16).

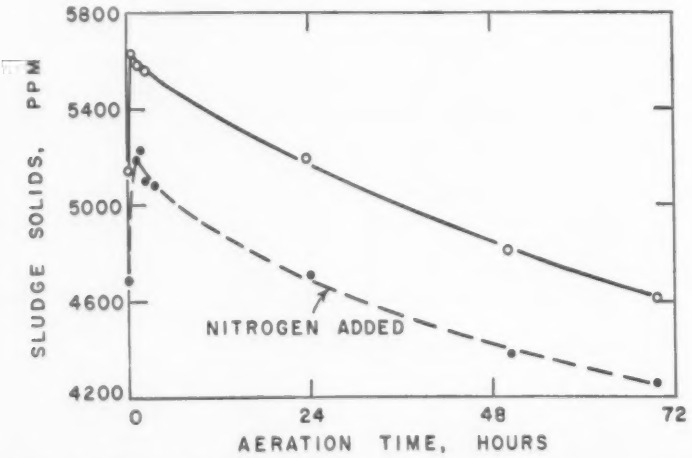

FIGURE 2.—Changes in sludge concentration during continuous aeration following whey addition (sludge cultivated 96 days on whey, with and without NH_4OH).

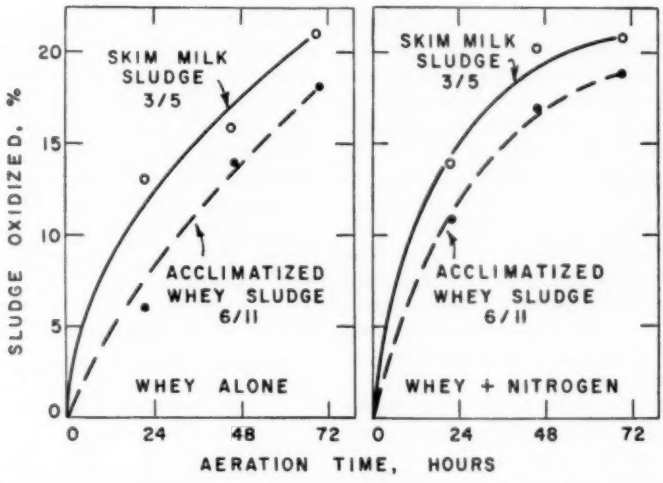

FIGURE 3.—Aerobic digestion of sludge immediately after whey feeding.

Nitrogen

Nitrogen determinations were made on sludge mixtures and clear filtrates collected and prepared during the course of the experiments. Samples were inactivated by the addition of concentrated H_2SO_4 and refrigerated until assayed by a semi-micro Kjeldahl method employing hydrogen peroxide and sulfuric acid digestion. The original sludge solution analyzed 200 ppm N, as compared to an estimated 234 ppm. Over the 72-hr aeration period, practically no increase in Kjeldahl-N occurred, even though N was added to the whey as ammonia.

The second run, made 21 days later after 15 feedings, showed practically the same N concentrations, yet the sludge concentrations had doubled. Excess N may have been oxidized to nitrates in the presence of excess organic matter, as had been demonstrated by Heukelekian (17).

The deterioration recognized in the 96-day sludges was reflected in nitrogen content. These sludges, which had begun to settle very poorly, contained 160 ppm N in the unsupplemented tank and 200 ppm in the other, although sludge solids measured 5,000 ppm. These sludges still actively removed whey from solution; however, their nitrogen contents were only 3.2 and 4.0 per cent instead of the accepted minimum of 7 per cent.

Discussion

Aerobic treatment of dilute whey wastes was successfully carried out in the laboratory. When 2,000 ppm sludge were used in treating 1,000 ppm whey waste under highly aerobic conditions, no additional nitrogen was needed to effect complete whey removal. Large quantities of sludge solids supply sufficient nitrogen from cell sources for the treatment of dilute whey. Although the COD:N ratio in milk is 18:1, whey can be treated with less nitrogen. A good source of N was shown by previous exploratory respirometer studies to be NH_4-N. Urea salts are a fair source, but nitrates were found of little use in oxidizing the lactose of whey. The nitrogen present in the sludge itself and in whey should be taken into consideration in calculating supplements.

The beneficial effect of nitrogen addition was illustrated during investigations in the 10,000-gal milk waste pilot

plant at Pennsylvania State University. When whey was accidentally discharged into the treatment unit, excessive foaming immediately occurred and sugar was not oxidized. Addition of 100 lb of ammonium sulfate to the aerator on the days when the creamery wasted 5,000 lb of whey permitted treatment operations to proceed. This whey contained 350 lb of solids. The amount of nitrogen added was sufficient to give a COD:N of 17:1 disregarding the N of the whey and of the seed sludge. One-half the quantity of $(NH_4)_2SO_4$ may have been ample.

It must be pointed out, that under actual plant conditions, unlike the laboratory experiments, a disposal unit would rarely receive pure whey solution for treatment. The raw waste from a cheese plant would most certainly contain floor washings, whole milk discharges, and probably some sanitary wastes. The introduction of these materials would be beneficial to the nutrient balance of the influent.

In pure whey studies, it was shown that a nitrogen supplement enhanced the rate of sludge oxidation, but under the laboratory schedule of daily whey feedings it was found that both supplemented and unsupplemented sludges gradually deteriorated and presented serious bulking problems within three months. Cheesemaking apparently removes from milk many known and unknown growth factors, leaving whey as an unbalanced food material for bacterial growth. Nitrogen alone replaces one of the most serious deficiencies, but in itself is incomplete supplementation. Other pure nutrient supplementation would be both impractical and probably incomplete. It is possible that periodic but judicious additions of milk itself may avoid the bulking problem.

Summary

Dilute whey wastes (1,000 ppm) were aerated in the presence of a sludge (2,000 ppm) rich in nitrogen. Whey of a COD:N ratio of 50:1 was treated as readily as whey supplemented with ammonium hydroxide to give a COD:N ratio of 30:1. A prolonged schedule of treating whey under laboratory conditions produced a change in the characteristics of the sludge. Sludge accumulation occurred as a result of impaired oxidation of intracellular material, although whey removal rates were not affected.

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GRADUATE ASSISTANTSHIPS

The Rice Institute now offers graduate work in sanitary engineering, leading to the Master of Science Degree, under the auspices of the Department of Civil Engineering. Students may participate in research activities on a part-time basis during the school term and full-time in the summer.

Graduate assistantships providing exemption from all fees and carrying a minimum stipend of $1,500 for the academic session are available. Summer employment is at commensurate salaries. Further information may be obtained by writing to A. W. Busch, Assistant Professor, Department of Civil Engineering, The Rice Institute, Houston 1, Texas.

BIO-OXIDATION SHORT COURSE

The Civil Engineering Department of Manhattan College will offer a one-week course on the Theory and Design of Biological Waste Treatment during the week of June 16, 1958.

The objective of the course is to present the fundamentals of bio-oxidation which will serve as a framework for the analysis, design, and operation of biological waste treatment facilities. Emphasis will be placed on applications of these principles to several wastes from industries, including pulp and paper, pharmaceutical, canning, and chemical.

All correspondence concerning this course should be addressed to W. Wesley Eckenfelder, Jr., Civil Engineering Department, Manhattan College, New York 71, N. Y.

CITY CONTROL OF INDUSTRIAL WASTES IN MUNICIPAL SEWERS *

By Ernest H. Campbell

Associate Director, Bureau of Governmental Research and Services, University of Washington, Seattle, Wash.

Municipalities in a rapidly growing section of the country, such as the Pacific Northwest, are necessarily confronted with an increasing number of requests for investigations and rulings with respect to the discharge of a variety of industrial wastes into municipal sewer systems. In view of the effort that now is being made to attract new industries to locate within the corporate limits of Pacific Northwest municipalities, the disposition of industrial waste becomes a matter of very real significance. Therefore it is imperative that cities and towns make certain they have in force ordinances containing appropriate provisions regulating industrial usage of municipal sewers and the necessary rules and regulations applicable to the disposition of industrial wastes.

The Function of Municipal Sewer Systems

At the outset it should be recognized that municipal sewer systems are designed primarily for the collection, transportation, and treatment of sanitary sewage. They are not usually designed for, or well adapted to, the collection and treatment of the many kinds of ever-changing waste products of industrial and commercial processes (1).

Classification of Industrial Wastes

The financial policy adopted by the legislative body of the various municipalities may vary with respect to the extent to which industry shall bear the cost of the disposition of industrial wastes. It has been widely recognized, however, that industrial wastes may be divided into four groups with respect to their disposal, and that such classification will help to determine equitable assessments. These four groups are the following:

1. Those wastes which can be discharged into sewers without any preliminary treatment. This category would include waste only in such a volume (continuous or periodic) that it does not materially increase the cost of sewer maintenance or treatment and has no injurious effect upon the sewers or sewage treatment facilities.

2. Those wastes which require some adjustment of the amount of flow but no preliminary treatment before disposal into sewers. This category would include wastes which are discharged intermittently and temporarily overtax the sewer capacity, such as discharges from swimming pools.

3. Those wastes which can be admitted into sewers after some preliminary treatment to eliminate or minimize their harmful effects. This category would include wastes containing acids, oils, grease, and other substances which tend to form deposits in the sewers or overload the treatment plant, such as discharges from canneries.

4. Those wastes which should not be discharged into sewers since they are of such a character as to disturb sewage treatment processes, occasion dam-

* Presented at the 1957 Annual Meeting, Pacific Northwest Sewage and Industrial Wastes Assn.; Seattle, Wash.; Oct. 24–26, 1957.

age to structures, or add unduly to the cost of operating the treatment plant. Wastes in this category would include live steam, scalding liquids, and volatile inflammable liquids or gases (2).

It is essential, in drafting the provisions in the municipal ordinance which relate to industrial wastes, to classify the wastes in the manner described in order to take into account financial considerations and accord fair and non-discriminatory treatment to industries generally. This procedure is also essential in order to safeguard the city against potential legal liability that might otherwise arise. In the state of Washington, the implementation of the plan adopted by a municipality, both by the original construction and by repair and maintenance of sewers, is a proprietary rather than a governmental function. Therefore, for any negligence in constructing or in maintaining sewers (especially when the act of the city is the proximate cause of the damage sustained) a city may be held liable.*

Conditions Precedent to Issuing Building Permits to Industries

Before a building permit is issued to an industry considering locating within a given municipality the applicant should be required by such municipality to submit to the appropriate city official data concerning the wastes it proposes to discharge to the city sewers. Data should include quantity, rate of discharge, type of wastes, proposed pre-treatment (if required to meet standards), a sample of the anticipated industrial waste, and the anticipated daily and monthly discharge volume. Satisfactory arrangements for waste disposal could then be made prior to the erection of the proposed plant.

Status of Industrial Waste Ordinances in Municipalities

At the present time a substantial number of Pacific Northwest municipalities have not enacted any ordinance or adopted rules and regulations with respect to the disposition of industrial wastes. Some cities that have enacted ordinances or adopted appropriate rules and regulations to this end have done so only after substantial damage to the sewer system and treatment structures has resulted from the introduction of industrial wastes into the municipal sewer system and damage suits have been instituted against the city. Moreover, in many of the municipalities that do have ordinances on industrial waste, there should be much more explicit, thorough, and comprehensive coverage of the subject of the regulation of industrial usage of municipal sewers than now exists in such ordinances. This would enable these municipalities to prepare for the anticipated industrial expansion in this region and to avoid possible misunderstandings on the part of industrial users and potential damage claims that might otherwise result. Many municipal ordinances that were adopted some time ago need to be re-examined in the light of current developments and needs so that the necessary changes, indicated by the accumulated experience in administering sewer ordinances, may be incorporated therein. In addition, there needs to be much more effective and systematic enforcement of existing ordinances. Maintenance of good records, with respect to what wastes are being admitted to the sewer system, should be required since this may become particularly important in the event of litigation.

It is recognized that, because of the

* *Hayes v. City of Vancouver*, 61 Wash. 536, 112 Pac. 498 (1911); *Boyer v. City of Tacoma*, 156 Wash. 280, 286 Pac. 659 (1930); *Muskatell v. Seattle*, 10 Wn. (2d) 221, 116 P. (2d) 363 (1941); and *Vittucci Importing Co. v. City of Seattle*, 72 Wash. 192, 194, 130 Pac. 109 (1913).

particular industries located in certain cities, such cities have special industrial waste problems. Some of these cities have enacted specific ordinances for the control of wastes from a particular industry, such as milk handling and processing. However, the enactment of ordinances on a case-to-case basis, without a general industrial waste ordinance and rules and regulations applicable thereto, leaves much to be desired and may result in discrimination with respect to certain industries.

Suggested Remedial Action

In considering what may be done to provide adequate ordinances and rules and regulations with respect to industrial waste, a number of matters should be kept in mind:

1. The classification of industrial wastes into the four groups previously mentioned may be indicated.

2. Attention should be given to the elimination of the objectionable aspects of corrosive wastes by controlled rate of discharge, neutralization, or other pretreatment, and to the preliminary treatment of other wastes, required because of their strength and character prior to admission to the municipal sewer system.

3. Due consideration should be given to the view expressed by many writers and authorities in this field that it is unreasonable for a municipality to exclude all industrial wastes from their sewers, particularly when acceptance will not increase the cost of sewer maintenance and will have no injurious effect upon the sewers or sewage treatment.

4. In the final analysis, the matter of the disposition of troublesome industrial wastes (other than those which must be prohibited from the municipal system because of characteristics which would create hazards, occasion physical damage, and interfere with the operation of the system) is a matter of cost. The policy as to what this cost amounts to and who is to pay it should be clearly determined.

5. Ordinances should include a provision which specifies that industrial wastes will be admitted to the municipal sewer system only pursuant to permission granted by a specifically designated municipal official.

6. The procedure for adequate pretreatment should be spelled out in detail.

7. The specific limits for objectionable characteristics of industrial wastes should be indicated (3).

8. Although it is recognized that the "Minimum Requirements for the Disposal of Industrial Wastes," adopted by the Washington Pollution Control Commission Aug. 2, 1950, apply primarily to waters of the state (*i.e.*, to rivers, streams, ponds, lakes, inland waters, underground waters, salt waters, and other surface waters and water courses within the jurisdiction of the state of Washington), nevertheless many of the provisions thereof might very well be considered by municipalities and adapted for inclusion in their ordinances and/or rules and regulations with respect to the disposition of industrial wastes in municipal sewer systems. It also should be noted that these pollution control minimum requirements provide that officials of cities, towns, and sewer districts are directly responsible for the control of oil discharged from their respective sewerage systems, and that ordinances should be enacted making it unlawful to dump or otherwise discharge oil into these sewer systems.

9. The Pollution Control Council Pacific Northwest Area Report, dated 1952, also contains minimum requirements for the prevention of industrial wastes pollution that should be taken into account. These relate to the waste disposal practices of slaughterhouses and meat packing plants, poultry killing and packing plants, milk and milk products plants, vegetable and fruit canneries, fish and shellfish canneries, wineries, breweries, saw mills, veneer

mills and other wood-handling plants, plants for processing oils and like material, tanneries, beet sugar factories, coal washeries, gravel washeries, flax processing plants, dehydration plants, potato and fruit processing plants, the metal industry plants, and pulp and paper mills.

10. In the state of Washington, all plans and specifications for the construction of new sewerage systems, sewage treatment or disposal plants or systems, or for improvements or extensions to existing sewerage systems or sewage treatment or disposal plants, are required by statute to be submitted to, and approved by, the Pollution Control Commission before construction thereof may commence. Therefore close coordination with the Pollution Control Commission and the State Department of Health is essential in formulating municipal ordinances relating to the disposal of industrial wastes. The rules and regulations of the Pollution Control Commission also require any owner or his authorized agent to submit for review and approval a preliminary report of any new or major improvements or additions to existing facilities used for the purpose of industrial waste disposal or treatment. Further, the final plans and specifications therefor must be submitted to, and receive the approval of, the Pollution Control Commission (4). The need for compliance with the applicable rules and regulations of the Pollution Control Commission and of the State Board of Health might very well be indicated in the ordinance.* In any event the cities and towns should obtain the opinion of the Pollution Control Commission and of the State Department of Health with respect to the industrial waste that their sewer system can accommodate.

11. Equitable charges must be established and provision must be made for paying for the sewers. This necessarily involves making an analysis of the BOD strength, the amount of flow, the quantity of solids, chemicals, and acids, and the general character of the effluent. The rate structure for disposal of wastes should be based upon periodic tests, usually on a monthly basis. This is preferable to a flat rate since the quantity of water discharged and the chemical character of the effluent may vary from month to month. Because of the variable factors involved in different industries, the service charge for the disposition of industrial wastes is usually determined on a negotiated basis in each individual case. Certain formulae have been prepared by engineering consulting firms for establishing such charges and these may be used as a guide in determining an equitable assessment.

Local Improvement District Assessments

From time to time, the question of establishing a local improvement district to assess the cost of the disposition of industrial wastes from large industries is raised. In the event this method of financing is employed, in the state of Washington at least, the assessment procedure must be based upon assessing property uniformly under the Local Improvement District Law upon the basis of benefits to that property regardless of the type of improvements thereon.† The assessment may not be based upon the quantity or character of the effluent; however, it is provided that 25 per cent of the actual improvements may be taken into account in fixing the ceiling of local improvement district assessments. The zone and termini method may be utilized for abutting property owners and area assessments for all property

* For example, a 1955 Washington statute (Ch. 90, 48 RCW (1955 Supp.)) provides that any person who conducts a commercial or industrial operation of any type which results in the disposal of solid or liquid waste into the waters of the state is required to obtain a permit from the Pollution Control Commission before he may dispose of such waste material.

† RCW 35.43.160 (1955 Supp.).

served by the trunk sewer line but not abutting upon it. Thus this would involve an ordinary trunk sewer with an enlarged district.

An assessment made under the Local Improvement District Law cannot be based upon the quantity of effluent discharged into the sewer system or the strength and character of such effluent as there is no authority for doing so under this law in the state of Washington. The quantity and nature of the effluent are factors, however, that should be taken into account in fixing the sewer service charge. In this manner large industries contribute their fair share of the cost of building and operating the sewage treatment plant, making additions and betterments thereto, and operating and maintaining the sewer system. The rate structure must be based upon reasonable classifications. In order to establish such classifications, the industrial waste should be analyzed and evaluated to determine its strength and character and the cost of treatment. Then industries whose industrial waste is comparable could be placed in a certain classification. The industrial waste of some plants will be of such a nature that they may necessarily have to be considered on an individual basis. After a Local Improvement District has been established, the city is not precluded from making an appropriate service charge based upon the quantity and character of the effluent merely because the original cost of the sewers serving them was paid for by local assessments according to special benefits.*

"Late Comer" (Deferred Benefit) Charges

A provision, such as Section 8 of Longview Ordinance No. 862 for Delayed Benefit Charges, may be established to take care of industries outside of the local improvement district which may desire to connect therewith at a later date. Under such a provision they are required to pay their fair share of the benefits received on the basis of contracts which are made a covenant running with the land. In contemplation of such contingencies, the city might deem it desirable to construct a larger size of trunk sewer than is immediately required to serve the needs of existing industries and to have the city itself assume a portion of the cost thereof for which it would be reimbursed subsequently, to some extent at least, by the "late-comer" charges to industries.†

A number of studies have been made with reference to sewer charges that would be very helpful in formulating

* See *Morse et al. v. Wise*, 37 Wn. (2d) 806, 811, 226 P. (2d) 214 (1951).

† See also Wenatchee Ordinance No. 1436 and Seattle Ordinance No. 83825. This Seattle ordinance is based upon the language of RCW 35.13.220 which authorizes the annexing city "to fix and collect charges to customers." Whether the courts will conclude that "charges" under the above statute embrace both the deferred benefit charges as well as service charges remains to be determined. Deferred benefit sewer charges have been sustained in some jurisdictions when they are reasonable and are equal in proportion to the footage to the amount paid by other persons whose property was within the corporate limits of the city at the time the trunk sewer line was constructed. See *City of Tulsa et al. v. Bell*, (Okl.), 278 Pac. 642 (1929); *Oliver et al. v. Water Works and Sanitary Sewer Board et al.*, (Ala.), 73 So. (2d) 552 (1954); *City of Fergus Falls v. Edison*, 94 Minn. 121, 102 N.W. 218 (1905); McQuillin, *Municipal Corporations*, (3rd ed.), Vol. 11, Sec. 31.30. See also *State ex rel. Stoeckle v. Jones*, 161 Ohio St. 391, 119 N.E. (2d) 834 (1954), in which an ordinance providing for a $300 sewer connection charge for permission to connect with a village sewer to be paid by owners who had improved their property at a time when they escaped with an inconsequential assessment, was sustained. In other jurisdictions, ordinances imposing deferred benefit sewer charges have been held to be invalid. See *City of Des Plaines v. Boeckenhauer et al.*, 383 Ill. 475, 50 N.W. (2d) 483 (1943). It remains to be seen what position the State Supreme Court will take with respect to the imposition of deferred benefit charges under such ordinances in the absence of enabling legislation.

a rate structure with respect to industrial wastes (5)(6)(7)(8).

Cooperation Between Cities and Industry

There is much to be said in favor of having at least a measure of regional uniformity among municipalities with respect to their policies for the acceptance and treatment or the rejection of industrial wastes. If the cities and towns of each of the states in the Pacific Northwest were requested to furnish a copy of their ordinances to a committee consisting of representatives of the officials of the cities and towns in the area and the management of local industry, much benefit would result. Through mutual discussion and cooperation between municipal officials and representatives of industry on such a committee, considerable progress could be made in the direction of improving industrial waste ordinances, in bringing them up to date, and in encouraging more municipalities to adopt ordinances on this subject. Furthermore, the recommendations of such a committee would be effective in designing ordinances and rules and regulations which would make maximum use of the municipal sewer systems for the wastes that can be handled by them. This would be mutually beneficial to industry and the municipalities. In addition, selected sewer ordinances of particular merit in municipalities outside of the Pacific Northwest could be obtained by the committee and studied.

Through such efforts, by discussion and cooperation, it is to be hoped that city officials and representatives of industry will reach an understanding concerning their mutual interest in industrial waste problems. This method of working together is far more likely to be productive of a satisfactory result than the alternative of having each city attempt, through the exercise of its police powers, to abate industrial waste situations which have already created a problem in the community.

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Stream Pollution

EVALUATION OF FEDERAL CONSTRUCTION GRANT PROGRAM UNDER PUBLIC LAW 660—PANEL DISCUSSION *

I. INTRODUCTION

By Milton P. Adams, *Leader*

Executive Secretary, Michigan Water Resources Commission, Lansing, Mich.

This is the third national convocation of state, interstate, federal administrators, and many others affected by the Federal Pollution Act of 1956, Public Law 660, 84th Congress. Two years ago many of the same people, but a smaller group, met in Atlantic City, when there was great concern as to the type of legislation that was going to be enacted by Congress. One year ago at Los Angeles, with the law in effect and the first year's appropriation made both for administrative grants and construction grants, much of the time was devoted to the discussion of priorities and other ways the states perform that part of their responsibilities under this Act.

At the Los Angeles meeting a motion was made and adopted, calling for a request to the Surgeon General for the establishment of an annual conference of state and interstate water pollution administrators. At the present time a committee is formally canvassing the sentiment of the various states as to their experiences with this law.

As an introduction, a word may be said about one state with which there is considerable familiarity. Michigan has ascertained the hard way one or two things that cannot be changed. For instance, after the first year's experience in allocating the money, and some being disappointed and few being pleased, it was felt that it might help if the rate and maximum amounts of grant be reduced, thereby making the money go farther. However, it has been stated in official communications that this plan is not possible. Therefore, the rule of 30 per cent or $250,000, whichever is smaller, is to be followed.

Since these funds are controversial terms of the Federal Law these pressure brought to bear for allocation of funds to certain districts. Under the terms of the Federal law these pressures cannot exert any influence. As a result the selections are based strictly on merit.

Another comment is that as an administrator of a state agency it is disturbing to have so much good time spent on ascertaining the few lucky people to whom the money goes.

* Presented at the 30th Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; Boston, Mass.; Oct. 7–10, 1957.

II. INDIANA EXPERIENCES

By B. A. Poole and O. H. Hert

Respectively, State Sanitary Engineer, and Special Projects Engineer, Division of Sanitary Engineering, Indiana State Board of Health, Indianapolis, Ind.

The Indiana sewage treatment plant construction picture of the past 15 months apparently is different from that being reported for most areas of the country. Table I shows the annual construction by fiscal years since July 1951 and an estimate of the projects that could go under construction by July 1960. This estimate is based on personal contact in the individual communities and includes an appraisal of the "readiness to go" of the public officials and the people, as well as the status of plans and specifications. Only three projects sold bonds and went under construction between July 1956 and July 1957. During the latter half of calendar 1956 all municipalities ready for construction wanted to wait for federal funds. Eleven projects were offered, and accepted, federal grants. Most of them took bids before the end of the fiscal year but not in time to sell bonds and actually start construction. Five of these projects had sold bonds by September 15, 1957.

Particular attention is directed to Columns 3 and 4 of Table I, which show the population served by new sewage treatment plants and the population of cities making additions to existing plants. It is believed that an indication of population served is a better measure of pollution abated than the more commonly used number of projects started or the cost of the projects.

Table II shows the Indiana projects that received grants from the 1956–57 Federal appropriation. By and large they were little projects. However, they may be fairly representative of the country as a whole, since the July 31, 1957 release of the Public Health Service shows that of the 487 projects receiving grants from the first year's appropriation only 48 were given $250,000.

In 1956 Indiana received additional applications for $1,652,000 in grants from 9 municipalities. One of these has proceeded to construction, the other eight are still pending. These

TABLE I.—Annual Construction Expenditures for Sewage Treatment Facilities in Indiana

Year	No. of Projects	Population Served (1950 Census)		Project Cost[1] (Million Dollars)	Estimated Federal Aid (Million Dollars)
		New Projects	Additions		
1951–52	6	11,076	—	3.823	0.783
1952–53	6	29,298	7,316	12.373	1.258
1953–54	14	177,214	65,858	22.022	2.005
1954–55	14	125,383	109,549	20.608	2.258
1955–56	13	43,863	470,798	30.275	2.071
1956–57	3	—	135,862	6.965	0.500
1956–57[2]	11	21,994	15,156	3.629	1.003
1957–58[3]	21	45,800	106,900	12.667	2.600
1958–59[3]	24	172,170	618,236	21.610	4.530
1959–60[3]	26	39,499	318,602	18.244	4.070

[1] Actual dollars.
[2] Projects allocated federal grant funds but not under construction July 1, 1957.
[3] Estimated projects and costs.

TABLE II.—Indiana Projects with Federal Grants 1956–57

Municipality	Population (1950 Census)	Total Project (Dollars)	Total Eligible Cost (Dollars)	Federal Share (Dollars)
Decatur	7,271	1,175,000	1,120,000	250,000
Tipton[1]	5,633	648,000	281,000	84,300
Winchester[1]	5,467	149,570	131,903	39,570
Huntingburg[1]	4,056	635,200	334,000	100,200
Monon	1,439	194,278	130,928	39,278
Alexandria[2]	5,147	897,061	668,160	200,448
Fremont	947	301,325	97,750	29,325
Jonesboro	1,973	413,781	295,937	88,781
Fairmount	2,646	496,649	322,166	96,649
LaGrange	1,892	256,840	212,800	63,840
Morristown[3]	679	144,124	34,566	10,370
Total	37,150	5,312,008	3,629,210	1,002,761

[1] Improvements to existing plants.
[2] Engineer's estimate—verified bids not received.
[3] Oxidation pond.

were being considered the latter part of 1957 with 17 new applications requesting $2,489,000 in grants. Thus, the total applications on hand would require about four times the amount of federal funds currently available.

The tightening of the bond market during the past several months has undoubtedly been a great factor in causing officials of the Indiana cities passed over on grant applications to want to defer construction and wait for "another chance at federal funds."

Table III indicates the interest rates on Indiana sewage works revenue bonds, and sanitary district bonds from 1951 to September 15, 1957. Seven bond issues were sold during the three-month period ended Oct. 1, 1957. Late in 1956 and to date of reporting in 1957 five towns have been unable to sell revenue bonds at interest rates as high as 5¼ per cent. Three of these have federal grant offers.

Table IV lists the bond sales of the Indianapolis Sanitary District since 1951 and shows a uniform picture of the climbing interest rate. This rise is more uniform than that of the preceding table because of a common basis for review of all the proposed bond issues.

Indiana experiences during the past 15-month period, ending Oct. 1, 1957,

TABLE III.—Interest Rates—Indiana Sewage Treatment Construction

Year	Bond Issue—All Projects (Dollars)	Interest Rate (per cent)			
		Sanitary District Bonds	Revenue Bonds		
			Minimum	Maximum	Weighted Average
1951–52	3,823,575	1.76	3.25	4.00	3.58
1952–53	12,372,615	2.15	3.38	4.40	4.04
1953–54	22,022,024	2.26	2.70	5.00	3.07
1954–55	20,607,597	2.13	2.37	4.50	2.94
1955–56	30,275,000	2.38	2.50	4.13	3.48
1956–57	6,909,000[1]	2.98	—	—	—
July 1–Oct. 1, 1957	4,928,000	—	4.5	5.25	4.93

[1] Sanitary district bonds only.

TABLE IV.—Sanitary District of Indianapolis Annual Bond Issues

Year	Bond Issues (Dollars)	Interest Rate (Per Cent)	Length of Issue (Years)
1951	1,350,000	1.88	32
1952	950,000	1.63	26
1952	2,460,000	1.88	22
1953	1,575,000	2.00	25
1953	3,750,000	2.37	30
1953	1,950,000	2.25	30
1954	250,000	2.13	25
1955	3,210,000	2.13	30
1956	17,970,000	2.38	30
1956	840,000	2.38	28
1956	1,500,000	2.75	30
1957	1,320,000	3.25	30
Total	37,125,000	—	—

and an appraisal of the current attitude of municipal officials, indicates a tremendous "selling job" must be done if the estimates of potential construction of the next three years are to be turned into actual construction. And these estimates must be met if the rate of pollution abatement established in 1953 to 1955 is to be maintained.

Conclusions

Based on the experiences in Indiana during the 15 months ending Oct. 1, 1957, in connection with the construction grants program of Public Law 660, the following conclusions are drawn:

1. Municipal sewage treatment plant construction in Indiana was deferred during the last half of calendar 1956 while city officials awaited the outcome of applications for federal grants.

2. Since January 1957 most cities and towns not receiving a grant have not proceeded because of the tight money market and the hope they would get a grant from current or future appropriations.

III. FLORIDA EXPERIENCES

By David B. Lee

Director, Bureau of Sanitary Engineering, Florida State Board of Health, Jacksonville, Fla.

First, a brief statement about the philosophy of sanitary engineers is in order. It is difficult to understand why sanitary engineers as a group are a pristine collection of individuals who are opposed to federal grants. It does not seem appropriate to take such an arbitrary stand not to want federal grants. Attention is called to the fact that this Public Law 660 is just one more tool needed to protect the greatest natural resource, water. One feeling is that water belongs to the state and this is believed to be true.

When an examination is made of the record of the pollution abatement, it is seen that instead of a decrease there has been an increase of pollution throughout the country as a whole. There does not seem to be justification to feel proud of this record, although in some areas the performance has been commendable.

In a look at the future it is easy to see that there will be serious problems. In comparison with conditions today, it is predicted that in the future this country will see 600 million people, plus a tremendous expansion of industry, and much unknown in the chemical environment.

As a "State's Righter" it is felt that a water pollution law is needed. Reality must be faced because a law appears inevitable. Such a law should be in an agency that understands the problems. It is not so important to debate whether there is agreement on Public Law 660 or any other details, such as Section 6 or the enforcement procedures, but it is believed that it is an important matter that the profes-

sion of engineering of this group must settle on the fundamental principles of the approach to this problem. It is time to stop leading the public and politicians and the people who pass laws to believe that the sanitary engineers who are the professionals in the water control field are in a state of utter confusion and disagreement. It appears as though that kind of impression is left every time a group gets together in Congress. It is time to get together and work out the necessary details.

Again, it is stated that Section 6 is just one more tool in the over-all picture of the program. It is necessary to evaluate this program thoroughly. In order to do this more time is needed to give it a fair test.

Discussing Florida, it is very much the same picture that has been mentioned in Indiana. In Florida, there have been 11 projects, all small, and only one out of the 11 under construction. Why? Because those 10 towns can not finance the other 70 per cent of the program. In this program, if all the money that the town asked for was obtained from the Federal Government, there could have been a program built amounting to better than 55 million dollars. So for every dollar that would have been obtained from grants the community would have put in 10 dollars. In the southeast it is much the same way. In a circulation of the southeast it was found that of the 118 projects, 9 were completed; 13 were 25 per cent completed; three were 50 per cent completed; three were 75 per cent completed; and 61 were ready to go under construction.

Therefore, rather than to condemn the program it is felt that further time is needed to evaluate the program.

One other point is offered. If the States knew they were going to have a 10-year program of federal grants they would be in a much better position to allocate and set up priorities and be in readiness to set up a program. It is believed that it is not the federal grant portion that is holding up this program. To amplify some of these statements the results of questions to others are offered. Engineers and bond houses that have sold bonds in Florida since 1950 were queried and the results show a definite pattern.

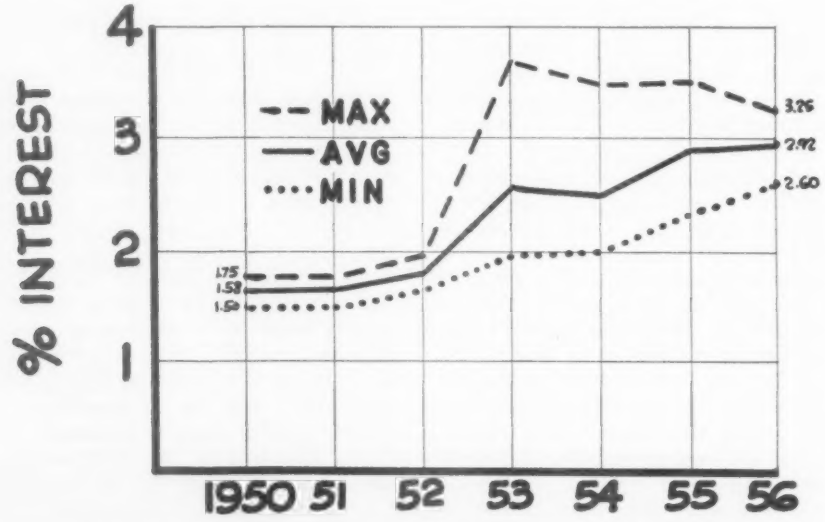

FIGURE 1.—Bond interest rates for Metcalf and Eddy projects, 1950–56.

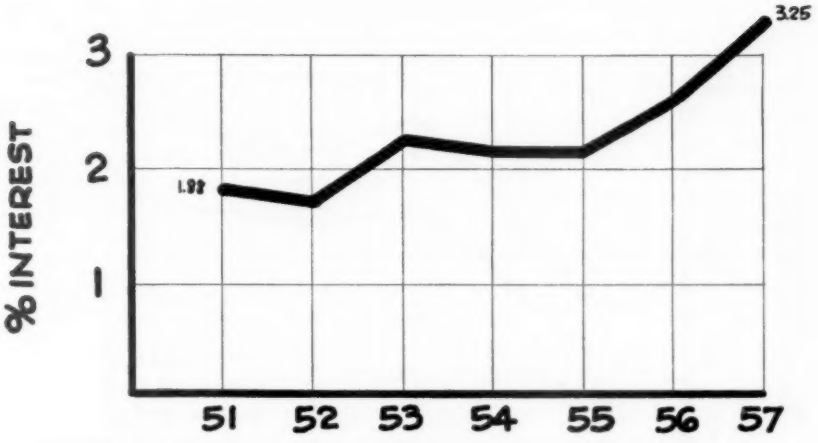

FIGURE 2.—Interest rate of annual bond issue—Sanitary District of Indianapolis, 1951–57.

Figure 1 shows the bond interest rates for Metcalf and Eddy sewerage projects from 1950 to 1956, giving minimum, average, and maximum rates. It is seen that the maximum interest rates reached a peak in 1953, while the general trend for average rates has been to rise, with the highest in 1956. It is not known why the maximum rates in the bond market were lowered in New England in 1956. This does not show data from 1957, which could be substantially different.

Figure 2 shows the pattern of the interest rate of the annual bond issue for the Sanitary District of Indianapolis from 1951 to 1957. A general increase is shown with a sharp upturn the last two years.

In Figure 3 there is contained a pic-

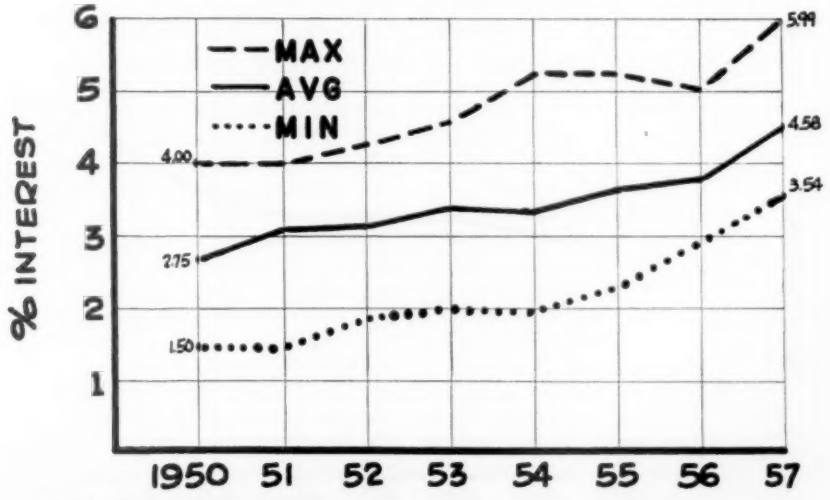

FIGURE 3.—Bond interest rates for a combination of water and sewerage projects, 1950–57.

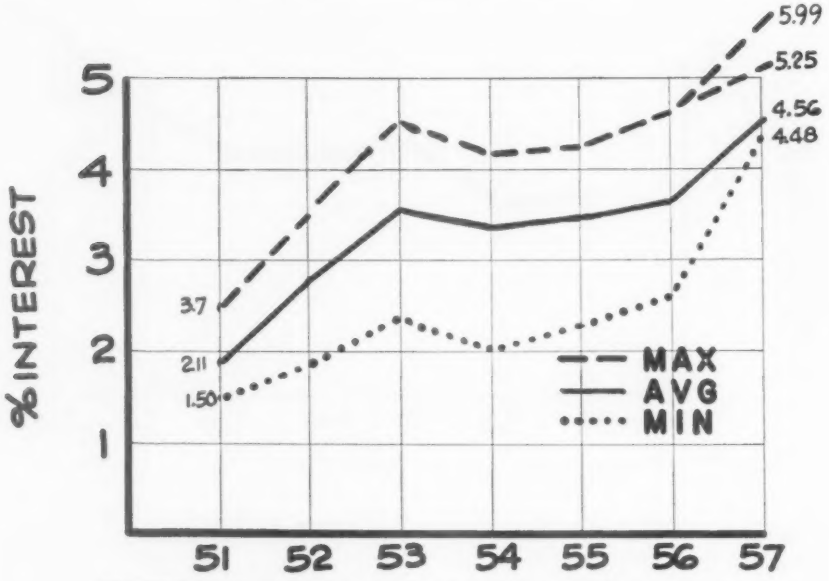

FIGURE 4.—Bond interest rates for basic sewage projects, 1951–57.

ture of the bond interest rates for combined water and sewerage projects. This also shows a generally rising trend and further shows a substantial variation between the minimum and maximum rates. From knowledge at first hand, the entire pattern is rising in Florida.

Figure 4 shows the bond interest rates for the basic sewage projects. It is seen that the interest rates reached a peak in 1953, lowered slightly, and then began a rise to the present time, with sharp increases in the last year.

Figure 5 shows the bond issue in-

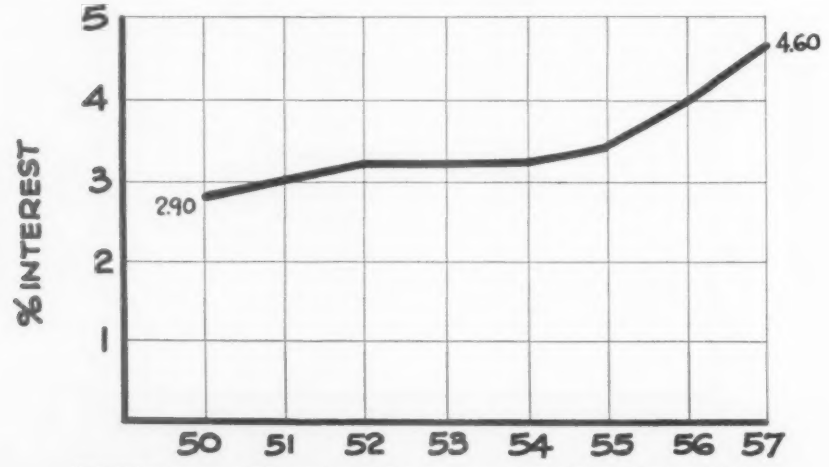

FIGURE 5.—Bond interest rates for a group of Florida projects, 1950–57.

terest rates for some projects in Florida from 1950 to 1957. A general increase is also indicated for these projects, including the most increases in the past two years.

To summarize, the rising bond interest rates appear to be one of the major impediments in the implementation of Public Law 660. To delay further the decisions to construct sewage treatment plants postpones the general issue and makes for eventual higher costs. It will be necessary to pay for these projects at some time and present indications are that this will be after the bond interest rates reach a level. The present trend shows that this interest level will be higher than at present; therefore, a delay will add to the costs.

Public Law 660 apppears to be a sound tool, provided that the parties affected can work out the details necessary to provide a completely workable law.

IV. CALIFORNIA EXPERIENCES

By Paul R. Bonderson

Executive Officer, California State Water Pollution Control Board, Sacramento, Calif.

California is honored to participate in this discussion and it is appropriate to attempt an evaluation of the effect of Public Law 660 at this early date because without a doubt this program will have a tremendous impact on water pollution control throughout the country.

Since it is believed that the Public Health Service administration of the program will have a great deal to do with its eventual success or failure, an evaluation of this phase is necessary. It is felt that the Public Health Service is to be commended for the excellence of the setting up of the program. There have been very few hitches and it is amazing in a program of this size that the operation has been so smooth. In processing applications many decisions have been made promptly and decisively. There is not always agreement with the decisions but they have been decisively made. Cooperation from regional officers has been tremendous and is much appreciated.

Construction Grants Program

In regard to the construction grant phase of Public Law 660 there are two sound conclusions that can be drawn at this time. First, there is a tremendous amount of interest by the cities in California in this program; and second, it is too early to evaluate conclusively the impact of grants on the level of construction.

Favorable Reaction

This first conclusion, that is the interest, is drawn from a number of things happening in California. First, the legislature in session last spring passed a million dollar grant program to parallel the Federal program. The Governor, however, vetoed the bill. Recently the League of California Citizens enacted a resolution urging and requesting that the grant program be continued at not less than the minimum level that is now being carried on.

In the first year there were 81 applications filed in California for almost 8 million dollars of Federal aid. The second year (1957) the number of applications were down to 64 but the amount requested was approximately 8.3 million dollars.

As to the second conclusion, relating to the inability to evaluate the impact of the program, this is due primarily to the priority system used during the first year in processing the applications. The California system gave a tremendous advantage to the communi-

ties ready to go and did not really give time to the unorganized community to be stimulated into undertaking new projects. It is the feeling that the over-all state-wide impact so far can probably best be summed up as being neutral. There has been a little positive activity. There is, unfortunately, indication of a negative nature. The grant program during the first year did speed consideration on a number of signings but they are of minor significance as far as the state-wide picture is concerned. Applications are now being processed for the present year's fund and it appears certain that several projects will be initiated this year as a result of the grant program.

Unfavorable Reaction

There has been a negative aspect of this program also. All 81 applicants last year were supposed to be for projects on which construction would be undertaken by July 1957. This was not the case as many did not start construction on or before this date. In fact, some of the projects that received certification for grants have yet to let their contracts. Twenty-four projects of the 81 applicants were certified for grants. This left 57 uncertified. Of the 64 projects that are being processed this year 31 are reapplications from communities that were not certified the first year. No community has indicated that they are holding up construction until they receive a grant. However, it is hoped that their actions do not speak louder than their words. It will be some time before it is definitely known whether some cities are procrastinating in hopes of receiving a grant.

Other Problems

There are other problems in California associated with the program and these will be listed but not discussed in detail.

The first is poorly prepared applications and documents. It is really discouraging to review applications in which the first pages are not filled out.

Second, establishing priorities has been difficult. The program requires much staff time and other important activities, therefore, have suffered. Some communities are unhappy over the ruling requiring the equivalent of primary treatment.

One of the most knotty problems, yet to be solved, is determining what is an intercepting sewer. In this regard there have been hundreds of suggestions, not all of them acceptable to parties concerned.

Research Program

A few comments seem appropriate on the research portion of P.L. 660. California for some time has been of the opinion that research should be expanded on the federal level. This opinion has not changed and it is believed that this feeling is general in all other states that participated in the Congressional hearing, before the enactment of P.L. 660. It was very disappointing that the research phase has been slighted by Congress. California's interest can be demonstrated by the fact it is using almost every dollar of the program grant for the support of research. The particular program receiving attention in California has to do with the problems associated with the ocean disposal of sewage. It is felt that California is making effective use of the program grant monies for research purposes. Unfortunately, it is doubtful whether their effective use of research program monies could be made because of inability to fill all authorized positions in recent years.

Summary

In summary, the administration of the program by the United States Public Health Service has been outstanding. However, it is disappointing that

the research phase has been slighted by Congress.

Program grant funds are being used effectively for research on ocean disposal of sewage.

There is a tremendous interest in the grant program by communities in California. Requests for grants are exceeding available funds by a ratio of four to one and that pattern is expected to continue.

Finally, it is too early to evaluate the impact of the Federal grants on the level of construction.

V. NEW YORK EXPERIENCES

By A. F. Dappert

Executive Secretary, New York State Water Pollution Control Board, Albany, N. Y.

Grants

New York State received $2,749,675 for allocation to municipalities for sewage treatment work construction from the 1956–57 Federal budget. While some 60 municipalities filed applications for these funds, only 37 applications were in such form that they could be considered for processing without substantial change or implementation. The formula of the Water Pollution Control Board, evaluating each project in terms of health benefits to be derived from the project and financial need of the municipality, was applied to these, and 24 projects were given priorities.

The total cost of these federally-aided projects is in excess of 13.75 million dollars. In addition it will be necessary for several communities to construct collection systems and bear the entire cost of these projects themselves as there is no Federal aid available for this.

The grants requested out of 1956–57 allocations totaled $2,824,842 or about $60,000 more than the appropriation. However, the actual offers amounted to $2,694,314 as the Public Health Service ruled certain portions of several applications as ineligible for Federal aid.

The law states that the grants shall be 30 per cent of the cost of the eligible portion of the project or $250,000, whichever is smaller. The offers here are about 19.5 per cent of the total project costs and average $112,000. Only four communities received the maximum grant allowance.

The law further states that at least 50 per cent of the grant money shall be to communities of less than 125,000 persons. In the New York allocation about 85 per cent of the funds went to communities of less than 125,000 population. However, $1,192,209 or 44.3 per cent of the funds went to villages of under 5,000 population.

Application Processing Procedures

The procedure for processing applications in New York may differ somewhat from that in other states. Briefly the New York procedure is as follows:

1. Applications are received and reviewed as to whether they cover projects eligible for Federal aid. Those that are rejected for this reason are returned to the applicant. Those that appear eligible are then checked for completeness and any necessary additional material is requested.

2. Completed applications are then sent to the Public Health Service for a determination of propriety for a Federal grant offer.

3. Periodically the eligible applications are assembled and scored according to a formula for priority. This formula gives equal weight to the

health benefits to be derived from the project and the financial status of the municipality. Under the health benefits are considered the health effects of the pollution on the receiving waters, the importance of this particular situation with reference to other pollutional situations in the basin, and other effects of the pollution on the receiving waters not directly related to health. Financial considerations include per capita cost of the total project, including items ineligible for Federal aid, per capita bonded indebtedness exclusive of school bonds, and the combined general and school tax rate per $1,000 assessed valuation on an equalized basis. Every application is rated in each of these six categories with a maximum value of 10 in each. These scores are then totaled and the projects are listed in a table with the highest number of points first. There are cases where the project cost is greater than the available debt margin. Projects in this group are given top priority. Priorities are assigned to cover the funds to be distributed at this time and applications not receiving a priority at this time are reconsidered in the succeeding groups of applicants.

Evaluation of the Program

After a year of operation it is appropriate to comment on the program evaluation. There is action toward the construction of sewage treatment plants in places which, it is believed, would never have been forthcoming without this program. Several of the municipalities that have moved ahead have been under pressure for several years without much apparent success. Other places would have gone ahead without Federal aid, but Federal aid probably has been a factor in speeding progress. Of course, the hardest thing to do was to turn down applications from places that had awarded contracts prior to the cutoff date of July 31, 1956. It is felt that some places that were ready to go ahead about the time the program was envisioned did hold back, with the idea that they might get funds. All in all, it is felt that the program has stimulated the construction of sewage treatment plants. While the extra work placed on official agencies is heavy, it is hoped that the program is continued.

In the matter of difficulties with the program, it is time-consuming from the administrative standpoint, but a way to provide relief to regulatory agencies from the extra work load is not apparent. All the administrative difficulties are with the applicants and their consulting engineers. It is a rare application that is received in such form that it can be processed immediately. The instructions appear to be clear but they are not followed. As a result, it may take as long as six months to collect the necessary data and supporting documents so that the application can be sent to the Public Health Service. Another touchy point deals with the time schedule placed on the application for having plans and specifications ready for bids and also the time when contracts will be awarded. It would appear that these schedules were not realistically assigned, since they are seldom met. There have been cases where these dates have passed before the engineer has been authorized to prepare the final plans and specifications.

One other interesting point in this connection is that this program has brought quite a number of new consulting engineering firms into the field of sewage treatment works. In New York State the plans are given a careful review following the recommendations set forth in the ten states "Standards for Sewage Works . . ." (1). It has taken considerable education on the part of the state agency to get these newcomers in this field to prepare their plans according to these standards.

When this Federal construction grants program was launched, it was felt that it was unfair in respect to taxpayers in states which get only a small return for their tax dollars when supporting such Federal aid programs. Also there seemed to be unfairness in respect to local taxpayers who have already paid or are paying for municipal sewage treatment plants already constructed. This thinking has not necessarily changed, but the facts are that the Federal construction grants program was launched and is now in its second year of operation.

If the program should be cut off at the end of this current fiscal year it is predicted that there would be several projects delayed by reason of the fact that the officials of some municipalities would hold off in the hope that somehow or other the program would be resumed in some succeeding year. Once a program of this kind is started it does not appear that there can be a return to the original status that prevailed before it was started. Municipalities are bound to look forward to some kind of continued Federal aid.

Future Recommendations

Therefore, taking a realistic view of the situation, the construction grants program is endorsed and a recommendation is offered for the appropriations to be increased to a level more commensurate with the requests for grants which are being made. In the case of New York State, if there were another two million dollars in the current allocation for 1957–58, it would be possible to grant priorities to practically all of the municipalities which thus far have filed applications for Federal aid during the 1956–57 and the 1957–58 fiscal years.

Further, it is felt that the rules should somehow be changed, which probably would require amendment of the law, such that Federal aid could be granted for construction of a portion of a pollution abatement project in advance of actual construction of an operable sewage treatment works. In this regard reference is made to several New York municipalities which have the problem of constructing long and expensive intercepting sewers as well as a sewage treatment plant, and the total cost of doing both is so great that the entire project must be set up on some kind of a stage basis. Municipalities in this position should be eligible for aid if they will build their needed intercepting sewers as a first stage project.

In consideration of the future, New York State received an allocation of $2,746,550 for the 1957–58 Federal fiscal year. Requests on hand considerably exceed this amount and there are known additional applications which will be filed in the near future. There are others which will be filed within two years. Priorities on the 1957–58 appropriation are being established and forwarded. Currently, administration is very much a problem. However, the responsibilities of the Public Health Service in the regional office are appreciated.

With due regard to the work load in the Public Health Service, it is suggested from the state's viewpoint that it would be helpful if procedures could be revised under which, after a state priority is given, there could then be more direct negotiations between each applicant and the Public Health Service; this might be more expeditious than having the state serve as intermediary in the operations.

Reference

1. "Standards for Sewage Works, Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, New York, Ohio, Pennsylvania, and Wisconsin." Upper Mississippi River Board of Public Health Engineers and Great Lakes Board of Public Health Engineers, May 1952 (partially revised July 1954).

VI. INTERSTATE AGENCY EXPERIENCES

By Joseph C. Knox

Secretary, New England Interstate Water Pollution Control Commission, Boston, Mass.

This assignment was to evaluate, from the viewpoint of interstate agencies, the effectiveness of the grant provisions of Public Law 660 in advancing water pollution control. Accordingly, the several interstate agencies have been contacted for their comments in this regard.

All the interstate agencies are in accord that the grants to state and interstate agencies for expansion of their programs have been of considerable aid. In addition to financing needed pollution control surveys and investigations, the grants are being used effectively in expanding research programs on waste treatment problems to an extent which otherwise would have been impossible.

The experiences of the interstate commissions in connection with construction grants to municipalities is naturally the sum total of the experiences of their member states. This information has been summarized by previous speakers on this panel. As anticipated when Public Law 660 was enacted, the construction programs in some states have been retarded and in others stimulated by the grants.

The situation in the New England Compact area follows the same pattern as throughout the country in that the construction grants program has been a deterrent in some states and an accelerator in others. Connecticut's program, for example, provided for eliminating the discharge of all untreated sewage into its waterways by 1962, but because of the limited allotment to Connecticut for grant purposes the goal cannot be attained as planned. On the other hand the grants are proving a stimulus to the programs in Maine, New Hampshire, and Vermont. These states, within recent years, enacted water pollution control legislation which provides for classification of all inland and tidal waters, followed by the installation of the necessary treatment facilities to meet the classifications. Laws were enacted by the 1957 Maine and Vermont Legislatures making available state grants of 20 per cent to supplement the Federal construction grants. In New Hampshire, similar legislation was defeated when the Senate President broke a tie vote on the measure. Such state-aid legislation could not be passed in Connecticut, Massachusetts, and Rhode Island because the majority of municipalities in these states have constructed treatment works at their own expense. New Hampshire has enacted legislation under which the state guarantees municipal bonds for sewage construction works, and the Vermont laws have been amended to require only a majority vote instead of a two-thirds vote for approval of bond issues for treatment plant construction.

The philosophy in New England has always been that pollution control was the responsibility of the municipalities and the states. It took the state water pollution control agencies from the end of PWA days in the 1930's until the early 1950's to convince municipalities that Federal subsidies were not and would not be available for construction purposes. Then the construction grant provision was inserted in the legislation which resulted in Public Law 660. This provision was opposed on the grounds that the appropriation proposed was inadequate and that previous experience had shown Congress had a faculty for initiating programs and then failing after a few years to

make the required appropriations. This situation occurred most recently in 1952 under Public Law 845. Should Congress fail to continue appropriations for grants, there would result a greater lag in treatment plant construction than that following the PWA program. Therefore, regardless of the philosophy concerning grants, it is incumbent on the pollution control agencies to make the grant program a success.

It was not the intent of Congress that Public Law 660 should curtail the program in some states. This has actually occurred and yet in some states the allotted funds are not being used. This situation certainly calls for modifications and revisions in the present statute to provide for more equitable distribution of funds to carry out the purpose of the law. Proposed amendments probably could best be formulated by a Conference of State Water Pollution Control Directors, the organization of which was recommended to the Public Health Service at the panel discussion on Public Law 660 at the Federation meeting in Los Angeles last year.

VII. FEDERAL EVALUATION

By Gordon E. McCallum

Chief, Water Supply and Water Pollution Control Program, Public Health Service, Washington, D. C.

Those of you who were at the Federation meeting in Los Angeles last year may recall that Mr. Hollis discussed the then new Federal Water Pollution Control Act. At that time there were outlined some of the things proposed to be done in implementing this legislation. At this time attention will be given to some of the things, particularly some of the new activities, that are under way.

New Activities

The job of getting a new program such as this started certainly impresses on one the many facets and complexities of a well-rounded water pollution control program. The variety of individual skills and activities which must be brought together these days amazes even those who are not entirely new to the field.

During the past year, the major job has been getting the construction grants program under way as quickly as possible with a minimum of red tape —and there has been considerable pleasure from the favorable reports that have come to Washington. The Public Health Service realizes that a primary reason for whatever success there has been is the cooperative and efficient manner in which the states undertook this new activity. This might well serve as an example of how a joint undertaking of this nature can be made to work.

The water pollution control organization in the Public Health Service was rather depleted at the time Public Law 660 was passed in July 1956. As a result, rebuilding the staff has been a major effort during the past year. It is now hoped that it will be possible to begin carrying the fair share of the load, along with the states.

Basic Water Quality Data

Last year a proposal to begin a cooperative program of collecting and analyzing basic data on water quality was mentioned. Many of you know about this work. One of the initial aims is to establish some 50 sampling stations on interstate streams which will be integrated into what is hoped

will be an expanding network to better maintain surveillance over the Nation's waters. These data will include not only conventional analyses but newer types of chemical and radioactive contaminants. The response to this activity has been almost universally favorable and it is gratifying to learn that several states are giving more attention to the collection and use of basic data as a guide in planning their programs.

Economics

Another field entered is economics. This activity is closely associated with the basic data work but not a part of it. The approach to the economics of water pollution is based on fundamental economic theory. An effort is being made to develop procedures for determining the costs of pollution in local areas or regions in order to show what must be spent for control. Economists and engineers on the Public Health Service staff are working with universities, Federal agencies, and other groups in the development of these techniques. It is expected that reports on this subject will be available soon.

There are at present research contracts with the University of Chicago's Economics Department, and Leland Stanford University for the development of methods for the economic evaluation of water pollution. Suitable means of measuring pollution damages to both public and private users are being sought. It is also a wish to find ways of appraising dollar benefits that would accrue to both public and private realms from the control of pollution.

Conference Step in Enforcement

There is now a device that is proving helpful in the solution of interstate pollution problems. The pre-enforcement conference step was added to the legislation as a result of recommendations by states that had found it effective. Even in as complicated and difficult a situation as the Potomac River, it has been found that getting the official agencies around a conference table is most helpful. Understandings have been reached and a timetable for correction agreed to in each of the conferences which has been held.

Water Quality Conservation

Another activity which is beginning is the water quality conservation project. Actually, this is a comprehensive study of a water pollution problem having interstate, regional, or national significance. The Water Pollution Control Advisory Board recently told the Surgeon General that there should be more concentration on this type of activity. At present there is one such study in progress in the Arkansas and Red River basins of the Southwest. There are several hundred miles of main streams and tributaries in these river systems that are of very limited use because of both man-made and natural pollution, principally from salts. Significantly, this is in an area of the country where water is already limited and water shortages pose serious problems.

This particular study is designed to determine the source of saline and other pollution; how they can be eliminated or controlled, and how much it will cost. It is an engineering survey combined with an economic analysis rather than the usual type of stream survey. There has been enthusiastic support for this undertaking from the business and industrial community.

Basic Research

Basic research—always of high priority—is being expanded as rapidly as resources permit. This research is concentrating on more efficient and, hopefully, cheaper methods of waste treatment and the charac-

teristics of certain new contaminants. In all, the research effort has been about doubled under P.L. 660, but it is still a very modest program.

Public Health Service Views

Other members of this panel have directed their discussions to construction grants. It may be difficult to determine at this time just how such a program, or some modification of it, may affect the lagging construction of needed municipal waste treatment works. For the country as a whole, results look encouraging. A recent complicating factor is the municipal bond market, reported to be the most unfavorable in 20 years.

However, in the long term, some way must be found to get the money to build the plants that will keep pollution out of the streams. Better methods of financing sewage treatment works, especially in metropolitan areas, need to be found. It has been proposed that Federal grants be contingent on communities in metropolitan areas getting together on sewage treatment construction. Would it not be more appropriate for the states themselves to consider this?

These are some of the things being done with the tools and funds that have been provided. Like the military, however, there may be a tendency to feel that there never is sufficient equipment to do the job. The construction grants provision in the Act, which has received so much attention, is, as one state official put it "just one more tool to use in attacking this problem." It may not be just the right one and certainly is not perfect; however, the fact that it exists without its being requested by anyone in the sanitary engineering profession, may be an indication that the people are a little ahead of the profession in what they want and what they are willing to spend.

Conservationist Influences

Altogether, it seems that the understanding and attitude of the general public is encouraging. The views of the conservationists, for example, are of particular interest—and there will be more from them and their friends, in the form of political action, in the years to come. It may very well be that the objectives they seek in water quality will be strikingly similar to those found necessary and economically feasible for many other water uses. They have often expressed the opinion that those in the health and water pollution control field fail to look ahead and consider the broader interests in water use. They point out that the old saying, "You can't have your job and fish too" is obsolete; it now may be possible to have both and the public is willing to pay for it. Although the conservationists' position may sometimes seem advanced, history may find they were right on water pollution, as it has belatedly found them to have been on so many other great issues.

Future Demands

There are many and growing indications that the people want the Nation's waters protected. This emphasizes the role of economics, which can no longer be ignored in water pollution control. Preliminary exploration in the economic field indicates that there must be considerably more spent than at present to protect the waters from pollution, and that such expenditures can be justified economically.

Everyone is becoming increasingly aware that by 1975—in just 18 short years—there will be 60 million new Americans. Most of these people will live in suburbs that do not yet exist. Their needs will have a terrific impact on industry. Water pollution is not

the least of the great problems they will pose. Although these challenges look formidable, there will be considerable resources with which to meet them.

Perhaps the greatest strength in the national water pollution control program today is that it is not just a single program. Instead, it represents the combined efforts of every jurisdiction of government, supported by large national organizations having state and local affiliates.

With continued cooperation, improved communications, and a better understanding of what each is trying to do, there should be full preparedness for the job ahead.

CONSTRUCTION GRANTS

The Department of Health, Education, and Welfare reports an increase of about $130 million in contracts to be let during the next few months under three Federally-aided construction programs. One of these programs is the grants for municipal waste treatment plants.

Contracts to be let this fiscal year for P. L. 660 construction grants will increase from the original estimate of $170 million to $215 million. The Federal share is $57 million.

From the program's inception to February 28, 1958, total applications numbered 1,818, of which grant offers have been made to 913, and the remaining 905 are pending. The total estimated project costs amount to $1,049 million, of which the total cost of grants requested is $164 million.

Of the total 913 projects to which grants have been made, 80 have been completed, 395 are under construction, and 438 have been approved and are awaiting construction.

The average population of applicant communities is 21,384.

It is estimated that annual Federal appropriations of $50 million will stimulate $250 million of total sewage treatment works projects costs. The estimated on-site payroll for this construction is $75 million which will support approximately 13,000 man-years of labor.

WRIGHT APPOINTED NEW ADVISER FOR BDSA

David L. Wright, Sales Administrator of the Badger Meter Company, Milwaukee, Wis., has accepted the appointment as Adviser to the Director of the Water and Sewerage Industry and Utilities Division of the Business and Defense Services Administration, U. S. Department of Commerce.

Mr. Wright is on loan from his company under a rotation system in which key business executives serve the Government without compensation for six months or longer. He succeeds Mr. Charles K. Bassett, Vice-President of the Buffalo Meter Company, Buffalo, N. Y., who has returned to his industrial post.

THE OPERATOR'S CORNER

CONDUCTED BY DONALD P. SCHIESSWOHL

1957 OPERATORS' FORUM *

W. D. HATFIELD, *Leader*

Superintendent, Sanitary District, Decatur, Ill.

This is the first of two sections of the forum, including grit chambers and primary settling, and sludge digestion. The second portion, dealing with activated sludge, trickling filters, and stabilization ponds will appear in The Operator's Corner of the May 1958 issue of THIS JOURNAL.

Chairman Hatfield:—The purpose of a forum is, of course, to get discussion from the floor. To stimulate this, a panel has been chosen and the members will present 5-min talks to initiate discussion on the subjects of grit chambers and primary settling, sludge digestion, activated sludge, trickling filters, and oxidation ponds.

Grit Chambers and Primary Settling

Richard F. Greeley, Associate Sanitary Engineer, Massachusetts Department of Public Health, Boston, Mass.:—I would like to start by talking about excessive hydraulic loadings. One of our principal problems in the plants here in Massachusetts is excessive hydraulic loadings of grit chambers and primary sedimentation tanks. We spend a considerable amount of time designing tanks, but are we spending enough time going back into the sewer systems to try to make them tight? During the last three or four years we have had extreme weather conditions in Massachusetts. In 1955 we had something like 18 in. of rain in two days. This year (1957) we have had an extreme drought, and we have not had more than 4 or 5 in. of rain in the last five or six months.

At one plant, built some years ago, every time it rains it flushes out the entire sewer system. It has a long intercepting sewer, and a medium rain will flush out all the grit from the grit chamber. This material enters the primary settling tanks and interferes with the entire operation. I have visited some sewage treatment plants where the sewage seems to be going out of the sewers and the expected flows are not being received at the treatment plants. At two of these plants the flows are only about one-third of what they normally are. As a result, the sewage solids are left in the sewers and the digesters cannot be operated properly.

With respect to hydraulic loading, there is one plant which normally averages 2 mgd and is now receiving only about 50 per cent of the normal storm water. The flow is running about 1 mgd. This has a decisive effect on the

* From transcript, 30th Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; Boston, Mass.; Oct. 7–10, 1957.

grit chambers and primary sedimentation units. In designing these tanks, a more or less average mean flow and certain sewage strengths were assumed. However, these conditions never seem to be obtained. There is always too much or too little. Should we go back and spend more money on the sewer system rather than on the sewage treatment plants? Does anyone have a particular problem in his town on excess flows?

J. Henry L. Giles, Deputy Director, Public Works Department, Hartford, Conn.:—I have been much interested in this particular phase of the hydraulics of sewage treatment plants over a number of years, and I can think of five or six instances in Connecticut where what Mr. Greeley has said has been quite evident. In other words, in some of the smaller institutional plants, for instance, a very aggravating condition prevails when the grit chamber does not settle the grit. At times of high flow the grit is not taken out, and it all goes into the settling tank where it collects. We did quite a bit to correct that in some of the later plants, such as at the University of Connecticut, and in the design of two or three smaller plants where we put in multiple units just as you would with a large treatment plant. In Hartford, for instance, they have multiple units, but in a smaller plant a lot of times an engineer doesn't think in terms of multiple units. However, it certainly is a big help. Three grit channels are used, 6 in., 12 in., and 18 in., so that for times of low flow and light flow the smaller grit chamber can be used. For normal flows the 12-in. chamber is used, and for higher flows the 18-in. chamber. In times of excessive storm flows all three channels can be used together. I mention this particularly because it has worked out so well, and I think every consulting engineer should think in terms of multiple units even for the small plant.

T. R. Haseltine, Partner, The Chester Engineers, Pittsburgh, Pa.:—Do you have 24-hr operation there? What if it rains in the night? Is there a man there all night to make a selection between the 12- and 18-in. grit chambers?

Mr. Giles:—That is always a difficult matter, of course. We have one operator on an 8-hr shift, but with what knowledge we have we do the best we can. At the University of Connecticut where we had a maximum wet weather flow of 1.0 to 1.2 mgd and 0.03 to 0.05 mgd for the minimum flow at night, the operator had to use his best judgment, normally using the 12-in. grit chamber. During the summer when the institution was closed, we used the smaller channel, and during the very wet weather, with the extremely high flows during the day, we used the large channel or a combination of channels.

Mr. Greeley:—Let me ask another question. What is done at small treatment plants that have operators there only 1 or 2 hr a day? There are a number of plants of this type. Of course, we get a lot of storms at night. How are you going to control the grit going through? The purpose of the grit chambers is to take out the grit to protect the sludge digesters and sludge handling equipment. In the small plants, should we be more concerned with this matter?

There are a couple of other questions I would like to throw out. How are the velocity control grit chambers working? This is always a problem —we design them for an average velocity of around 1 fps, but do they always work like that ? We have minimum flows at night. These low flows have a tendency to deposit organic material; in the daytime the high flows have a tendency to wash some of the grit through.

Another problem is the handling of the grit cleaners. In these velocity control grit chambers the material that comes out is not too clean, and one of

the problems we get into from a public health point of view is how to dispose of the material. You put it in a dump area, and it has a tendency to decompose and produce an odor nuisance and health hazard.

Recently an aerated grit chamber was installed in Massachusetts. Should we give more consideration to this type of treatment? I believe the material that comes out is much cleaner. I do not have any experience with this type of unit. I did have some experience with an aerated grease removal tank at a military installation which did not have a grit chamber. The grease removal unit settled out the sand quite effectively.

W. W. Mathews, Superintendent, Gary Sanitary District, Gary, Ind.:—The Gary Sanitary District has installed some interceptors with rubber gaskets in the joints. These have proven their efficiency and, with one sewer below ground water level, not enough water leaked in to run an infiltration test.

Grit and grit removal is a problem in Gary. With a sandy terrain and infiltration through lateral sewer joints (all sewers are not as water tight as noted above) excessive quantities of sand get into the sewer system. Where average grit removal at sewage treatment plants throughout this country may range from 1.5 to 3.5 cu ft/mil gal, at Gary this has been as high as 8 cu ft/mil gal on an annual basis. On test runs the highest rate of removal was 3.3 cu yd/mil gal. It is not uncommon to have removals of 1 cu yd/mil gal. This causes excessive wear on comminutors, raw sewage pump impellers, and grit removal equipment. It has been found necessary to cover raw sewage pump impellers with rubber approximately ⅛ in. thick to prevent wear and to keep down maintenance costs.

Raw sludge supply presents another problem at the Gary plant. Many sewers in Gary have been laid on limiting grades. During dry weather flow solids tend to be deposited in the lateral sewers. At such times the sludge coming to the plant decreases in quantity per day until there may be only enough in the primary clarifiers to permit pumping into each of the primary digesters ½ hr per shift. Experience has shown that to maintain normal gas production two hours pumping per shift is necessary. A light rain, not a washout, will loosen this sludge so that it will start moving to the treatment plant and at times it has been necessary to pump four hours per shift to keep sludge from building up excessively in the primary clarifiers. With a minimum amount of sludge being received, gas production decreases and necessitates the purchase of either power or utility gas. With sludge flowing in at a high rate, gas production increases to such an extent that it becomes necessary to turn on the waste gas burner. Another factor has entered into this problem; gas production, total and average, has been tapering downward or holding about level since 1953, the year when highest total production was reached. Total for that year was 63,036,650 cu ft.

In 1957 a total of 58,407,170 cu ft was produced. In the intervening years total production was below this level. This same difficulty is encountered at other treatment plants.

Mr. Giles:—The subject of grit chambers is pretty close to our hearts in Connecticut because we have found in the past that we need grit chambers for practically every treatment plant, even though the flow was supposed to be entirely domestic sewage. There have been some very fine articles printed in the Federation Journal over the years discussing the essentials of variable widths in grit chambers. We use these variable widths in combination with the Parshall flume so that not only do you get increased widths, but you get increased depth and increased flow. That is why we have so

much flexibility in some of these smaller plants where we have widely variable flows.

Earl R. Howard, Executive Engineer, Metropolitan District Bureau of Public Works, Hartford, Conn.:—At Hartford we have four grit chambers with a flow header and a large dial in the grit collection house which is divided into four sections. Control is by manual operation. We use them to maintain a velocity of about 1 fps through each chamber. The flow is 40 mgd.

More recently we built a plant in East Hartford where we have mechanical grit cleaning equipment, chain and bucket type. This permits a rewashing cycle, which is part of your problem on cleanliness. Downstream from these channels we have a Parshall flume so that our flow is well controlled; there is no serious accumulation of grit.

In the opening remarks mention was made of flows that jump from nothing in dry weather to three or four times that in wet weather. This calls for better sewage construction initially for the taxpayers' money. It seems to me in some of these localities there is such a tremendous flow variation that it would be well to go back in the sewer system and get the bad spots repaired.

Bill Wallace, Field Engineer, Fischer and Porter Company, Pittsburgh, Pa.:—I have had some experience with rectangular grit removal basins. During low flows they deposited material that you had to put on a dump, oil it, flame it, and then bury it to keep insects away. On high flow you got a definite carryover of the grit, and I have the feeling more and more that the aerated grit chambers are going to be the answer.

John J. Wirts, Superintendent, Easterly Sewage Treatment Plant, Cleveland Ohio:—In 1952 we used a geologist to identify our grit. In the construction of a turnpike interchange the contractor's drainings from his excavations were getting into the main intercepting tunnel. The geologist identified the crystal structures as material from these excavations and we did get a judgment in court for damages for the cost of removing the grit from the tunnel. So in Cleveland we do have grit—a great deal of it.

Chairman Hatfield:—Has anyone any real operating experience on the newer aerated grit chambers?

C. E. Drummond, Jr., Consulting Engineer, Wiedeman and Singleton, Atlanta, Ga.:—Undoubtedly, there are many here who have had much more experience than we have had with aerated grit chambers. However, five or six years ago we came to the conclusion that aerated grit chambers probably offered the best chance of beating the problem of large washes of grit from storms; also at average or minimum flows. As you all know, of course, the overflow from aerated grit chambers has very little effect on the depth of flow in the tank itself as compared with most conventional types of grit removal units. The chief difficulty has been in getting equipment which will remove the grit. I believe there is very little question but that the aerated grit chamber will provide as fine a washing of grit as is necessary in any plant.

In my part of the country we have come to adopt the regular bucket chain type elevator for most of these installations. There is always present some industrial waste matter from meat packing or textile plants which makes it impossible to remove grit with the ordinary ejector. In extremely large installations in this part of the country and in the Middle West they use a clam shell. We have had to resort to its use in one small plant with a flow of 5 or 6 mgd.

We feel that the aerated grit chambers have proven themselves over the past five or six years, particularly if we can get the grit out.

Carl F. Hodgkinson, Chief, Water Pollution Control, Kansas State Board of Health, Topeka, Kans.:—It has been the experience in Kansas, for the small to medium-sized plant, where the population ranges from 5,000 to 20,000, that the velocity control grit chamber produces a better grit than the aerated grit chamber. For the small plant below this range, as far as I know, there is no effective grit chamber. You have to rely on tightening up the sewer system.

Mr. Giles:—In New Britain, Conn., they have a chemical treatment plant for 10 to 12 mgd. The plant was built without a grit chamber. However, there was a large aerated flocculation tank ahead of the settling tanks. In a very short time they had 6 to 8 ft of grit in the flocculation tank. It makes a wonderful aerated grit chamber, and depending on the weather, of course, they have to remove 100 to 150 cu yd of grit as frequently as once a month. I am not familiar with their experience during 1955, but I imagine they had some terrific grit removals during those heavy storm flows. Actually they have a by-pass line which they can use during cleaning and a bucket crane to take out large quantities of grit.

E. B. Cobb, Consulting Engineer, Metcalf and Eddy, Boston, Mass.:—If Frank Flood were here he would have a lot to say about aerated grit chambers. He has been an exponent of them. I myself have supervised the design of plants with them at Newport, R. I., and Manchester, Conn. As far as I can tell, they have been successful in removing the grit. They are not very critical so far as the velocity flow through them is concerned.

Using the catch basin type ejector for cleaning, it is necessary to drop the hose in the grit hopper and provide agitation, to pump the grit out of them. One trouble we ran into was that some people thought we could do that without dewatering the chamber. That is not possible, and it is best to lower the water to within 1 or 2 ft of the bottom. As far as I know today, we have had pretty good luck using these ejector pumps to clean the grit chamber.

From the Floor:—An aerated grit chamber was built some years ago at the Urbana-Champaign Sanitary District sewage treatment plant. To show how uncritical some technical factors are, they designed it around the use of a hydrocane. The bottom of the grit chamber was designed so that the crane could remove the sludge directly. They built a rather large chamber and the flows vary quite a bit in range so that they had quite a bit of air. The air supply is quite variable so that for low flows they can increase the air and thereby increase some of the turbulence in the chamber. When the grit settles to the bottom, their grit removal is simple. They simply lower the hydrocrane into the chamber and take it out as they please.

Sludge Digestion

Harry E. Schlenz, President, Pacific Flush Tank Company, Chicago, Ill.:—In the matter of sludge digestion, we want to talk about operational problems, with particular emphasis on plant loadings for the digestion unit. In my visits during the past year at a number of sewage works meetings, particularly the short-school type, I have been privileged to discuss digester operating problems with the operators. Based on these discussions I want to emphasize a few things that have come to the front, especially from operators who are just starting to operate their plants.

First of all, we have always felt that the digester should be a sort of "take-up" in the plant, and sometimes I think it is too much of a take-up. It takes up the failures of the grit chambers, with the result that sand and grit builds up in the digester over periods of time, and then we have to take the

sand and grit out. It also provides a storage capacity for other features in the plant which is important. At the same time the operator has to give quite an assist to the work that is being done in the digester.

In many cases, particularly in the newer plants, I find that the operator is slow to realize that digestion is a highly biological process, as well as mechanical; and he does not quite understand what he is trying to accomplish in the digester or how what he is trying to do affects the action in the digester.

TABLE I.—Procedures for Starting Sludge Digestion

Starting volume	Use least capacity available. In multiple tank installation—start the digestion in one tank only. In floating cover installations—fill the tank only sufficiently to float the cover. Use fresh raw sewage or water for filling.
	Caution—If an existing "sour" digester is to be restarted remove the sour contents completely and have inside walls and bottom thoroughly cleaned.
Temperature control	Initially heat contents to approximately 95° F. Maintain temperature uniform within 3° F (±).
Seeding culture	Seeding not absolutely necessary, but will hasten start of digestion action. Use sludge and/or digester liquor from a nearby digestion installation showing an active methane digestion. (Normal gas being produced and contents low in volatile acids.)
	Desired Quantity—Approximately 0.5 per cent (dry weight) of weight of liquid in the tank.
Sludge feed	In feeding, add no more than 10 per cent of the anticipated ultimate daily load each day. When the gas produced is 50 per cent of that calculated from the volatile solids added (approximately 5 cu ft/lb of dry volatile solids), and the volatile acids do not rise sharply, increase the feed by 50 to 100 per cent of initial feed daily until the ultimate load is reached.
Contents recirculation	Recirculate digester contents daily. At start, turn over the complete tank contents (bottom to top) for a 2-hr period at least once daily. Recirculation for external heating with suction taken from point about one-third of side water depth from bottom to top of liquid.
Volatile acids determination	Make volatile acids determination daily before adding feed. Continue daily determination until ultimate load is reached. (See "Standard Methods.") Volatile acids should not exceed 2,000 ppm. If volatile acids concentration shows continued increase, or digestion does not start, reduce or interrupt feed of raw sludge.
Gas yield	Measure and record gas production daily. Check CO_2 content of gas. (Simple rough determinations are sufficient.) Should expect approximately 10 cu ft/lb of volatile solids added in raw feed per day.

When the ultimate calculated load for one digester is reached, other digesters in a multiple tank installation will be easily started by transferring a limited amount of the best digested sludge and the overflow liquor from the first (initially started) digester to provide an active seeding culture.

We do know the process is a biological one, and we are learning more and more about the organisms that are involved. They are rather slow to build up from the time of the first seeding until a good active culture is produced. These digester organisms are quite different from other types of organisms that build up rather rapidly, and we have to treat them differently.

Some years ago Dr. Buswell and I prepared an outline (Table I) for starting up the operation of a digester for waste treatment where the period of digestion—the period of holding—was in the nature of 1½ days, and we knew we had to do many things differently than for those cases where adequate capacity was available. I have been using this procedure in recent years with operators, and I find if they follow it they avoid some of the starting difficulties. One important consideration is the matter of temperature control. We are gradually realizing the fact that we should not start digesters cold. If the tank is filled up with a lot of cold material that is available to digest some day, then there will be all the familiar problems when finally it is ready to digest.

By starting a digester initially with a small volume of sludge or liquid heated to an optimum temperature and by limiting the increments of feed of raw sludge, such problems may be avoided. Some will take exception to my statements about limiting the feed of sludge to 10 per cent of the normal ultimate daily loading until such time as there is evidence of digestion. I am not suggesting that we should add the equivalent of 10 per cent and wait a week and then add some more. I am saying we should put in small increments of sludge until we see good evidence of digestion. The percentage can be varied because in many places larger quantities are fed without any difficulties.

Referring to the matter of loadings, there has been considerable confusion in our interpretation of the work of experimenters and plant operators, in comparison with capacity requirements as set forth by state boards of health and other agencies. In Table II I have tried to record pertinent data on sludge digestion relative to digester loadings. Although there has not been any attempt to group the data in accordance with the nature of the experiment, you will note that the data as recorded involves pilot-scale experiments, carefully controlled plant-sized experiments, and, finally, normally operating plants operated with high digester loadings. Reference to the loading of volatile solids, as recorded in columns 8 and 9, indicates the obvious fact that the highest loadings are possible with laboratory-scale experiments, followed by pilot-size operations, and, finally, carefully controlled plant-scale experiments. It is not logical to attempt to apply loading factors obtained from small-scale pilot plant experiments to the design of full plant-scale operations without considering many other factors.

To summarize, I would say that in operating a plant where an operator has a sufficiently trained staff to provide careful digester control, it is not difficult to get loadings of volatile solids (in pounds per cubic foot per day) in the range of 0.15 to 0.2. In the case of pilot experiments, these loadings have gone up into the range of 0.3 lb per cfd, and some of them to the 0.4-range. Dr. Buswell had a laboratory experiment up to or beyond the range of 0.9 lb per cfd. It is possible to obtain these high loadings with a carefully controlled type of waste and carefully controlled laboratory work. On the other hand, if the per cent reduction in volatile solids is compared with what is normally expected it will be found that as the loadings go up, even in these carefully controlled experiments, the per cent reduction of volatile solids is reduced considerably below that normally ex-

TABLE II.—Tabulation of Pertinent Data from Articles on Sludge Digestion

Author or Experimenter	Location of Experiment	Period of Data		Nature of Experiment			Volatile Loading (lb/cu ft/day)		Per Cent Volatile in Raw	Per Cent Reduction in Volatile			Detention in Days		Gas (cu ft / lb of volatile added)		Remarks	
		Year	Period*	Scale	Type of Sludge	Primary Volume (cu ft)	Primary	Primary & Secondary		Primary	Primary & Secondary	Normally Expected	Primary	Primary & Secondary	Primary	Total		
Morgan, F.P.	Iowa City, Iowa	1953	10	Pilot	Primary & trick. filter sludge	150	0.277	—	62.7	47.0	—	47.5	8.7	—	8.85	—	Capacity stated as 0.39 cu ft per capita. Lagoons suggested for additional capacity.	
	Iowa City, Iowa	1953	1			150	0.253	—	71.3	51.2	—	68.0	8.9	—	9.24	—		
Blodgett, J.H.	Columbus, Ohio	1953	4	One full digester	Primary & act. sludge	106,000	0.171	—	59.75	32.0	—	49.0	14.4	—	7.1	—	No control digester. Comparison of loading with all other units.	
Forrest, T.H.	Erie, Pa.	1954	11	One full digester	Primary	125,000	(0.155)†	—	(65.0)†	(55.0)†	—	55.0	—	—	—	—	Guarantee stated as 0.13 lb volatile added per day.	
Torpey, W.N.	Bowery Bay Plant, New York, N. Y.	1953	7.5	Plant	Primary & modified act. sludge	180,000	0.18	—	74.5	42.6	50.1	73.0	13.3	—	8.5	10.0	Sludge barged to sea.	
		1953	25 days	Pilot		6	0.42	0.21	73.6	52.0	53.8	71.0	4.7	9.4	8.6	9.6	Selected period on basis of suggested 5-day digestion by Torpey.	
Garber, W.F.	Hyperion Plant, Los Angeles, Calif.	1953	6	Battery of two primary and one secondary	Primary & modified act. sludge	677,000	0.119	0.09	76.5	56.4	59.6	77.0	25.7	38.5	10.7	10.9	Single loading	Mesophilic digestion 100° F.
		1953	6				0.249	0.155	76.7	50.7	55.2	77.0	14.2	22.6	9.6	9.9	Double loading	
			12				0.128	0.085	75.4	53.5	55.6	76.0	23.5	35.3	9.5	10.0	Single loading	Thermophilic digestion 120° F.
			9	Two primaries			0.239	—	76.6	54.4	—	77.0	12.5	—	8.3	—	Double loading	

* Months unless noted. † Calculated.

TABLE II.—Tabulation of Pertinent Data from Articles on Sludge Digestion (cont.)

Author or Experimenter	Location of Experiment	Period of Data		Nature of Experiment			Volatile Loading (lb/cu ft/day)		Per Cent Volatile in Raw	Per Cent Reduction in Volatile			Detention in Days		Gas (cu ft/lb of volatile added)		Remarks
		Year	Period*	Scale	Type of Sludge	Primary Volume (cu ft)	Primary	Primary & Secondary		Primary	Primary & Secondary	Normally Expected	Primary	Primary & Secondary	Primary	Total	
Buswell, A.M.	Pekin, Ill.	Prior to 1950	10 years	Plant (three stage)	Yeast waste	95,000	0.324	0.108†	80±	80.0	—	—	3.3	9.9	5.0	—	Mesophilic 95° F.
	Laboratory		—	Laboratory	Rye waste	—	0.846	—	91.0	90.0	—	—	2.0	—	8.24	—	Thermophilic 130° F.
Schlenz, H.E.	Cedar Rapids, Iowa	1936	8	Two full digesters	Primary & trick. filter	150,000	0.15	0.075	78.0	76.0	86.0	80.0	20.2	30.3	7.8	9.9	Normal plant operation with the available capacity.
		1942	12				0.197	0.098	80.0	80.0	89.0	84.0	(15.8)	(23.7)	—	—	
	Cincinnati, Ohio	1954	12 days	Plant	Primary	74,700	0.223	0.110	52.8	25.0	36.7	31.0	13.6	27.5	7.25	8.39	—
Upper Mississippi & Great Lakes Boards of Public Health Engineers	Ten State Standards	1951	Full digestion and storage	Full capacity	Primary	—	—	0.042	—	—	—	—	—	52.1	—	—	Recommended minimum as calculated from cubic feet per capita standards. Includes full digestion and storage, basis of land drying.
					Primary & trick. filter	—	—	0.042	—	—	—	—	—	41.6	—	—	
					Primary & act. sludge	—	—	0.033	—	—	—	—	—	40.0	—	—	

* Months unless noted. † Three stage.

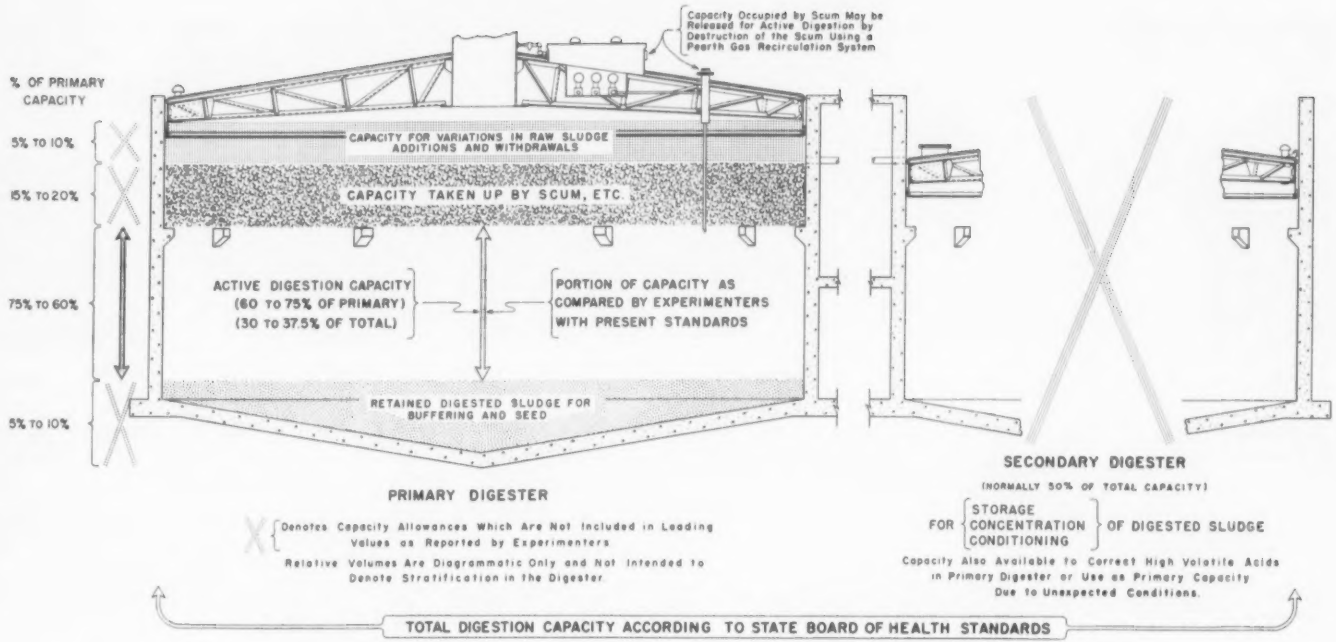
Capacity Occupied by Scum May be Released for Active Digestion by Destruction of the Scum Using a Pearth Gas Recirculation System
% OF PRIMARY CAPACITY
5% TO 10%
15% TO 20%
75% TO 60%
5% TO 10%
CAPACITY FOR VARIATIONS IN RAW SLUDGE ADDITIONS AND WITHDRAWALS
CAPACITY TAKEN UP BY SCUM, ETC.
ACTIVE DIGESTION CAPACITY (60 TO 75% OF PRIMARY) (30 TO 37.5% OF TOTAL)
PORTION OF CAPACITY AS COMPARED BY EXPERIMENTERS WITH PRESENT STANDARDS
RETAINED DIGESTED SLUDGE FOR BUFFERING AND SEED
PRIMARY DIGESTER
SECONDARY DIGESTER
(NORMALLY 50% OF TOTAL CAPACITY)
FOR STORAGE CONCENTRATION CONDITIONING OF DIGESTED SLUDGE
Denotes Capacity Allowances Which Are Not Included in Loading Values as Reported by Experimenters
Relative Volumes Are Diagrammatic Only and Not Intended to Denote Stratification in the Digester.
Capacity Also Available to Correct High Volatile Acids in Primary Digester or Use as Primary Capacity Due to Unexpected Conditions.
TOTAL DIGESTION CAPACITY ACCORDING TO STATE BOARD OF HEALTH STANDARDS

FIGURE 1.—Diagrammatic interpretation of normal design standards for digester capacity as compared with capacities reported by experimenters.

pected. This demonstrates the law of decreasing results.

In going over some of the various articles and controversies on the matter of digestion tank loadings, one always finds reference made to the standard as set up by the state boards of health and other agencies that are guiding digester design. If a digester system were designed in accordance with recognized standards, it could be represented graphically as a 100-per cent system, as shown in Figure 1. Assume in this digester system that one-half of the capacity serves a purpose other than active digestion. It is the capacity that allows us to operate sludge disposal facilities. This part of the capacity the experimenters do not concern themselves with because they are talking about the active digestion system. Now, if we take the other 50 per cent of the capacity, starting at the top, we have from 5 to 10 per cent of the capacity used to take care of variations in the amounts of sludge in and out. Next, we frequently have a capacity that is taken up by scum and debris. This scum capacity may amount to 15 to 20 per cent of this half capacity. Then there is that part of the capacity which I put down as reserve and for which I use a figure amounting to 5 to 10 per cent of this digester volume. This is the capacity reserved for sludge that is retained in the system as a buffer in case some unusual waste gets in the system. Some of this sludge may be ready for removal, but it is effective to have it stored up in the system. What does that leave us with? It leaves us with that portion I call the active digestion capacity. This amounts to 60 to 70 per cent of the half capacity, or from 30 to 37 per cent of the total capacity as compared with state boards of health standards. When the digester capacity is analyzed in this way and it is seen that those working on carefully controlled experiments are reporting the results of this portion of the digester system, then practice and laboratory are not too far apart. This gives us an answer as to why in some cases we talk about loadings that look very low and in other cases we talk about loadings that look relatively too high. We are not talking about the same thing. We are not able to operate our plants in general as experimental plants because there are too many other considerations that come into the system.

Philip F. Morgan, Professor, College of Engineering, State University of Iowa, Iowa City, Iowa:—Since the subject is sludge digestion and my specialty is high-rate digestion, I shall confine my remarks accordingly.

First I want to establish a basis for talking about high-rate digestion; I think the proper definition of a high-rate system is any system whereby the biological phase of digestion is carried on in one unit or one digester, and the mechanical phase of separation of the liquid from the sludge is carried on in another unit, either preceding or following the digestion phase. In addition to this, I think that in a high-rate system there must be a homogeneous mixture in the biological system; in other words, it must be completely the same from the top to the bottom. This is necessary so that the sewage solids, as they enter the tank, immediately come in contact with digesting sludge where they get seeding action so that the biological phase starts at once and there is no storage of raw solids in the biological unit. In other words, we have a biological unit that is completely active.

Another point is that when you have one tank that is completely the same throughout, the operator has better control over the digestion process. If he takes a sample to run volatile acids, pH, or solids, or whatever control tests he wishes, the sample he takes represents the entire tank. There is no question of whether the sample represents the top or the middle or the bottom.

Another point is that when the entire biological unit is active, it is not

necessary to reserve storage space for grit or scum on the bottom or the top because the biological unit is the one that is controlled. The problem of the grit, of course, can be taken care of separately. The other holding tank, the so-called secondary digester, then becomes primarily a sedimentation unit and not truly a digesting unit.

I believe that the development of the high-rate digestion idea of doing the biological work in one tank follows the pattern developed in other sewage treatment processes, such as high-rate trickling filters and high-rate activated sludge, in which we are trying to carry on biological treatment under better controlled conditions in a smaller volume of tank structure. It is the volume of the tank structure, of course, that costs money today. Now when we do this in any of the high-rate systems we have better control; by better control, we mean more control. Now when I say that, I can visualize a conference like this a generation ago. A comment was made—quoting from a textbook of the day—that an Imhoff tank did not have much future in sewage treatment because it was too complicated and that a septic tank was far better. People object to change and like to see things stay the way they are. But I think changes and progress will be made when the change results in better control so that the man running the plant knows what he is doing, when there are savings in cost of operation, and a better product results. The modern sewage treatment plant is indeed a manufacturing process. We must try to carry on the treatment at the least total cost to the taxpayer, and that means the least capital cost and operations cost combined.

Arthur M. Buswell, Research Professor, University of Florida, Gainesville, Fla.:—I think that the speakers have covered the subject quite adequately. However, I would like to define what we mean by the digestive capacity. With respect to the high-rate digester, I am in complete accord with what Professor Morgan has said. If you have thorough agitation, you certainly can operate at a much higher rate.

An operator asked me the other day: "What do you do in case the digester seems to be getting stuck?" I said, "Circulate very extensively, as much as possible." I think in many cases that is the answer.

I had a request the other day about how you would start the secondary digester. That floored me for a moment because I never thought of that particular thing as a problem, and I do not believe it is, except that the secondary digester should be filled previously with raw sewage and heated to the temperature that the primary digester is held at so that it is available for back circulation. Ordinarily a considerable percentage of the digestion has taken place in the first tank. I believe in earlier years they reported that 50 per cent of the digestion occurred in the first 24 hr.

One thing more about the secondary digester—I have always regarded it as insurance. Certainly, most of the digestion should take place in the primary digester; the secondary provides part of the liquid for back circulation in the case of a high volatile acids condition and insures against the necessity of discharging a sour mass of material in case the primary digester gets stuck. In two or three designs, the secondary digester has been much smaller than the primary; or one preferred design is two primaries and one secondary. In such a case, if necessary, the secondary can be made a primary in case one of the primaries becomes acid.

Mr. Masterson, Consulting Engineer, Cincinnati, Ohio:—Mention was made about a sewage treatment plant being the same as a manufacturing or industrial plant. We consider that in a sense an error, and in today's design of sewage plants we are working away

from fancy design, toward better control of the operation in digesters. Do not forget that we cannot keep up with the demand for operators to take over the operation of these plants.

Clair N. Sawyer, Professor of Sanitary Chemistry, Massachusetts Institute of Technology, Cambridge, Mass.:—As many of you know, professors are often accused of being behind the times as to what is going on in the operators' field. I was quite surprised to note the recommendation to apply only about 10 per cent of the anticipated load to a digester when starting it up. I have labored under the impression all these years that one of the reasons for the design of a conventional digester is so that the moment you started your plant up you could accommodate 100 per cent of the sludge flow and not have to be by-passing it to the river.

One of the things that has always bothered me about the development of the high-rate digestion process was that we are going to make these tanks one-quarter or one-half of the volume that we would provide if we were using conventional digesters. I was fearful that the state health department people would say, "Well now, you cannot put in such a unit until you have demonstrated how you can start such a digester without by-passing sludge to the river after your plant has gone into operation." Those of us who are interested in research try to get the answers to these problems; so we have been working on this matter of starting high-rate digesters, the problem that many of you are going to have to face. How are these digesters going to be started? Will we use a program of starting similar to that which we have been given to start digesters of the conventional type? We have been working on this problem, and have found that, if we first fill the digester with sewage and bring it up to temperature, we can put it under full load with the sludge, and, by proper pH control get the digester operating properly.

Fred G. Nelson, Director, Sanitary Technical Division, Dorr-Oliver, Inc., Stamford, Conn.:—There is one thing I think could well be added to Mr. Schlenz's comments on digester volume. That is the fact that some of the active part of the digester actually is handling nothing but water. The thing that I think we should keep in mind is that if we can concentrate the sludge to the point that we can get the least water in the raw sludge, we can greatly increase the digestive capacity.

Ralph H. Baker, Jr., Sanitary Engineer, Florida State Board of Health, Jacksonville, Fla.:—One of the difficult tasks on the part of the health department officials is education. We may have a facility which the city council feels is a new facility, but some of the people that were in on the construction and the initial building of it do not feel that it is operated either as an industry or a business.

Education is one thing that we need. We can talk about first-stage and second-stage digestion; we can talk about the efficiencies, pro and con, of aerated grit chambers. However, if we would study the number of man-hours and the number of personnel that the various type plants need and try to work out some livable wage for the operators, in the long run we would accomplish a real purpose. That is the biggest problem in Florida—not the discussions and conferences with designers or consulting engineers, because we can work them out. The problem is in trying to educate municipal officials to get a livable wage for the operators so that they can efficiently operate the treatment facilities that we have and that are being built so fast that we cannot get good men to handle them.

James M. Brown, Jr., Superintendent, Sewage Treatment Plant, Westchester County, N. Y.:—Two years ago at the New Rochelle sewage treatment

plant we started the digesters with about 60 to 70 per cent of the full load. We did not have to handle much sludge in the beginning and the digesters started successfully. I think the answer to why we got by without any trouble is because the digesters were of conventional type and lightly loaded. My main point is that we have four digesters that were all designed alike. Therefore, one or more of them could be used as secondary digesters. I believe it is important to provide secondary digesting capacity.

We have draft tubes on the digesters to prevent the formation of scum. If the draft tubes are operated, they keep the scum from developing, although a very poor supernatant results—so bad that we cut down the amount of time that the mixers were being operated. When we opened the digester, we found 5 to 6 ft of scum. We kept the mixers running constantly for six weeks. Then we opened the digesters again and found absolutely no scum at all. Because they were stirred up, there was no line of demarcation between sludge and supernatant. Therefore, the supernatant was so poor that we were using the primary settling tanks as secondary sludge digesters. Consequently, we had to use two of the digesters as secondaries and leave the mixers off. By this means we have been able to keep the primary digesters stirred up, and therefore we are able to alleviate the scum condition and provide a suitable supernatant from the secondary digesters because we do not have to keep the secondary tanks stirred since the scum problem is not going to be so critical. I think the need for secondary digestion is one that is very important. The levels of the primary digesters are very critical for, if the level is too high, the mixers do not function properly to relieve scum.

Professor Buswell:—The subject of initial feeding is perhaps a little ambiguous. If you add 10 per cent of the anticipated sludge load to a digester which is heated to the proper temperature and seeded, and you find that you get half of the anticipated gas or calculated gas, then the next day you have to add 20 per cent of the sludge load; and if you still continue to get gas, you add 40 per cent; and if gas production continues you keep increasing the sludge load. In a relatively short time you are adding the full load considerably under 20 days. I believe that at Cincinnati when the four digesters were cleaned out and reseeded that within considerably less than 20 days one tank was taking the full load, or four times its design load.

Mr. Schlenz:—When a panel discussion speaker has 5 min to start a subject like digestion, there is likely to be considerable misunderstanding. I would say to Clair Sawyer that I have seen operators try to do the sort of thing that he says, but the trouble is Clair Sawyer is not there holding the operator's hand. I would much rather have the operator go carefully even if he has a lot of digestion tank capacity. Capacity is not the answer; it is a matter of getting a culture started. Of course, if the operator can get a good seed sludge from some place, part of his problems are over because he has got something started.

I am afraid in presenting a rough symbolic digester, like I did in discussing the use of tank capacity, some might think I am talking about a stratified tank. The sections mentioned were merely portions of a tank by relative volume. I could have gone still further and said that we can get rid of the scum and turn the volume it occupies into an active capacity. The destruction of scum can be accomplished by effective mixing by means of gas recirculation. The main thing I was trying to get across was to clarify the basis of any discussion on digester volume so that we all talk about the same thing. Are we talking about a digester system which would

include some of Fred Nelson's preliminary dewatering and would include Phil Morgan's facilities for storing the sludge as against just talking about the active digester capacity?

If we have the opportunity of having the operating staff backed up by good chemists at the treatment plants, I know that we can design on the basis of considerably higher loadings than state boards of health suggest. But the trouble is we do not have such extensive staffs at most of the plants. It is important to consider that the treatment plant operator is confronted with many problems which are not anticipated by designers, nor by those reporting their findings from carefully controlled experiments. Without advance warning, wastes which are toxic to biological action may be received in the raw sewage and will retard the normal action in the digestion system. Dave Backmeyer reported on the procedures he had to follow in resuming the operation of the digestion system at the Little Miami treatment plant at Cincinnati, Ohio, after the raw sludge feed was interrupted due to flood water conditions. These floods caused discontinuation of the operation of the sludge settling units for a period of about 30 days. Since the digester system was operating effectively at a high sludge loading at the time of the interruption, he assumed that he could safely resume the full load when sludge was again available. However, he found that a resumption of the full load of solids resulted in a rapid increase in volatile acids in the digester system and it was necessary to resort to procedures as recommended for the initial starting of digesters. This meant a low feed of 10 per cent the first day and 20 per cent the next day, etc.

George Martin, Superintendent of the Green Bay, Wisconsin, plant, reports that when he is operating his digesters at a higher than normal loading, he finds it necessary to anticipate an interruption of the raw solids feed of as short a period as three days.

Professor Morgan:—I made my opening comments on the basis of my past experience in working with digestion. I would like to make my closing comments as a member of the City Council of Iowa City. I have been a member of the City Council for the past two years, and I have been actively interested in the Iowa City sewage treatment plant for the last 10 years.

This problem of always saying you cannot get a qualified man always irks me. Iowa City has a qualified superintendent. He is a graduate engineer. He has been there 10 years. The plant is completely paid for. A year ago we added a rather large pumping station. We paid for it out of the earnings. This year we are adding facilities for gas mixing in the primary digesters and also new heating facilities. We are paying for these out of earnings. The plant today is in better shape than the day it was built because we have a superintendent there who looks into the problem of why something does not work and he does not repair it with "hay wire," but investigates the cause the the problem and solves it. As a city councilman, I think one of the greatest problems we have is that the story is not being carried to the council. I am sure that most councils—it is certainly true of Iowa City—want to spend the taxpayers' money as wisely as possible. They are willing to give money to any department that shows by proper use of that money they will save money for the city in the long run. If, by spending money now for the proper operation of the sewage treatment plant, we can save a million dollars in maintenance and reconstruction a little later, I think most councils will go along with the request. It is hard to sell; but it has been done in Iowa City.

TIPS AND QUIPS

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The potential hazard of shock from 110-v circuits should be well-known to operating personnel. In order to reduce this danger when using auxiliary lighting, a low-voltage portable light system has been placed on the market.

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Gasket Joint for Cast Iron Pipe

Announcement is made of a newly developed molded rubber ring gasket for use with a cast iron pipe having a specially designed bell end. One section of the gasket is composed of hard rubber to provide a strong shoulder for centering the pipe; the other section is a softer rubber for ease in assembling and to provide sealing at maximum deflections. Metal contact strips are molded or fastened into the gasket to provide sufficient contact for the use of electrical pipe thawing in cold climates.

For installation the gasket is lubricated, inserted in the pipe, and the pipe shoved "home." This single gasket-type joint is known as "Fastite," a product of the American Cast Iron Pipe Company, Birmingham, Ala.

Sewer Maintenance

The value of having a program of preventive sewer maintenance was immediately apparent to the reorganized municipal government of Peoria, Ill. Prior to 1953, sewers were never cleaned; action was taken only upon complaint. The sewer department now owns modern equipment and cleans 12 to 16 miles of sewers each year to keep the city's 250 miles of sewers in good order.

A good sewer maintenance program is a mark of a progressive municipal government. The city administration that depends upon action only when complaints are received is due for an eventual rude awakening by the electorate.

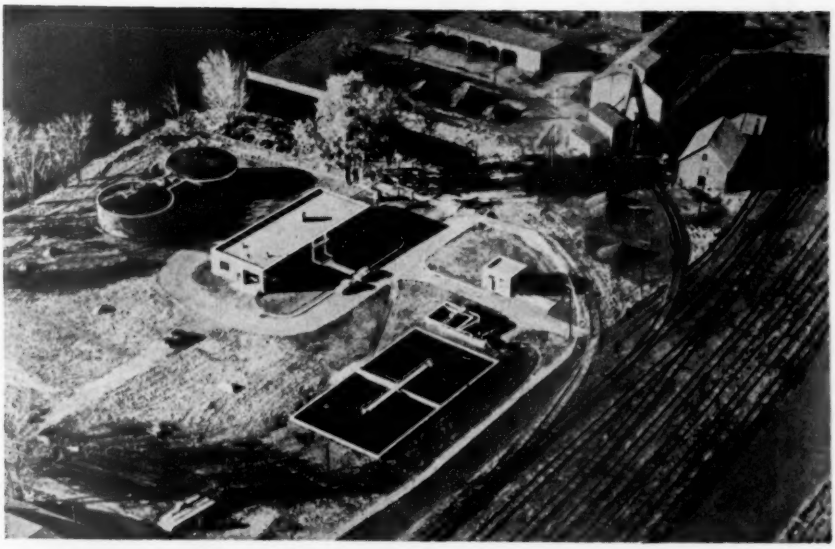
Tunnel Problems

Hot water, oil, and gas were among the hazards encountered during construction of interceptor sewer tunnels for the Allegheny County Sanitary Authority at Pittsburgh, Pa. Of the 69 miles of interceptor sewers, 30.5 miles are being built in tunnels, varying from 40 to 500 ft below the ground surface.

In some areas the water seeping into the tunnel is hot—so hot that it heats the liner plates, after they are in place, to a degree that would cause burns to the workers if they came in contact with them. Investigation has indicated that the water probably comes from the steel mills by seeping through the rock formation below the mills. In another section, oil seeped through the rock crevices, but oil wells were not in evidence. One suggestion was that the oil resulted from the cleaning of tanks in an oil storage area.

During the boring of one tunnel a capped 12-in. gas well was encountered 100 ft below the surface. Fortunately the tunnel ventilating system prevented any damage from the gas and the well was capped immediately.

Most of our troubles come from things we do ourselves, rather than from things others do to us. Therefore, keep very quiet about them.



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S-13

Proceedings of Member Associations

OKLAHOMA WATER, SEWAGE AND INDUSTRIAL WASTES CONFERENCE

Industrial Wastes Conference

The 8th Oklahoma Industrial Wastes Conference was held at Oklahoma State University, Stillwater, Okla., September 25 and 26, 1957. The Industrial Wastes Section of the Oklahoma Water, Sewage and Industrial Wastes Conference contained a full 2-day meeting devoted to problems in industrial wastes, and attracted an attendance from a wide part of the country. Refinery wastes were featured throughout the program.

Among the technical papers of interest to those in the sewage and industrial wastes field were:

"A Water Pollution Survey," by Herbert Pahren, Sanitary Engineer, Robert A. Taft Sanitary Engineering Center, U. S. Public Health Service, Cincinnati, Ohio; and "Discussion," by Dr. Troy Dorris, Professor of Zoology, Oklahoma State University.

"Air Flotation of Refinery Wastes." by Dr. William J. Katz, Chain Belt Co., Milwaukee, Wis.

"Radiological Waste Disposal," by Earnest F. Gloyna, Associate Professor of Sanitary Engineering, University of Texas, Austin, Tex.

"Biological Reduction of Chromates and Oil Wastes," by A. J. Krell, Technical Director, Reliance Chemicals

(*Continued on page 156a*)

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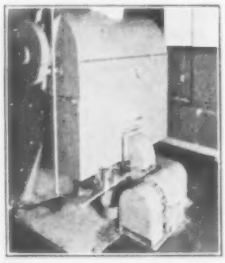

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"An Activated Sludge Plant for the Treatment of Phenolic Wastes," by R. C. Allred, Continental Oil Co., Ponca City, Okla.

"Measures of the Pollutional Strength of Refinery Wastes," by F. J. Ludzack, F. M. Middleton, and M. B. Ettinger, Robert A. Taft Sanitary Engineering Center, U. S. Public Health Service, Cincinnati, Ohio.

"Problems of Modern Industrial Wastes," by Harry Kramer, Robert A. Taft Sanitary Engineering Center, U. S. Public Health Service, Cincinnati, Ohio.

"Legal Aspects of Pollution Control in Oklahoma," by Richard M. Huff, Assistant Attorney General, State of Oklahoma, Oklahoma City, Okla.

Water and Sewage Short Course

The 31st Oklahoma Water and Sewage Short Course was held at Oklahoma State University, Stillwater, Okla., November 18–22, 1957. Attendance was recorded as 127.

Sewage works fundamentals were covered in sessions lasting two days. Individual speakers talked on the following subjects: introduction to sewage treatment, operating principles of septic and Imhoff tanks, primary settling and sludge removal, preliminary and auxiliary treatment of sewage, sludge digestion, maintenance and repair of sewerage systems, trickling filters, aeration, laboratory control, records, sewer capacities, stabilization ponds, maintenance of equipment and pipe materials.

The Oklahoma Water, Sewage and Industrial Wastes Conference offered an examination for those desiring to qualify for Grades "A," "B," and "C" operation certificates.

Technical papers of general interest included discussions on sewage slimes, Federal water pollution control policy, the role of water and sewage works personnel in disaster relief, public rela-

(*Continued on page 158a*)

Equipment and Supply Lines

Pneumatic Transmission System—Bulletin 750 describes "Laminair," a pneumatic transmission mechanism that produces an output air pressure which varies directly with flow through a Venturi tube, flow nozzle or orifice plate.—Simplex Valve and Meter Co., 7 East Orange St., Lancaster, Pa.

pH Buffer Solutions—Handy sealed vapor-proof packets of buffer agents are available for quickly making up 500 ml of buffer solution for pH meter use. The packets are available for various pH's. Polyethylene squeeze bottles with convenient dispenser tops can be provided for mixing and holding the buffer solution.—Analytical Measurements, Inc., Chatham, N. J.

Valve Lubricants—Information on lubricants for plug valves is available in Bulletin V-220, Rev. 1.—Rockwell Manufacturing Co., 400 North Lexington Ave., Pittsburgh 8, Pa.

Meters, Valves, and Regulators—The 28-page catalog C-5000, Rev. 8, describes meters, valves, and regulators for gas and liquid service. Descriptive material is well-illustrated.—Rockwell Manufacturing Co., 400 North Lexington Ave., Pittsburgh 8, Pa.

Process Equipment—A new 32-page bulletin, entitled "Products and Processes," illustrates a complete line of water and waste treatment equipment. —Infilco Inc., Tucson, Ariz.

High-Head Pump—A pneumatic diaphragm-type pump is now available for dewatering operations or other uses where a high head (100 ft) is encountered. The pump is capable of handling abrasive materials and up to 60 per cent solids.—The Layton Co., Inc., 4749 S. Whitnall Ave., Cudahy, Wis.

Stainless Steel Venturi Tubes—Venturi tubes with stainless steel metering sections are currently available.—Vector Manufacturing Co., Inc., 433 Old York Rd., Jenkintown, Pa.

Stirrers, Mixers, and Shakers—Equipment for performing the basic laboratory operations of stirring, mixing, and shaking is described in 16-page Bulletin FS-264.—Fisher Scientific Co., 717 Forbes St., Pittsburgh 19, Pa.

Pressure Transmitters—Pressure transmitters with interchangable parts and no contamination of the measuring elements by the primary fluid flows are described in Folio No. 56–13 A (Differential Pressure Transmitters) and Folio No. 56–12 (Pneumatic Pressure Transmitters).—Republic Flow Meters Co., 2240 Diversey Parkway, Chicago 47, Ill.

Flexible Valves—Catalog No. FL-1116 presents a complete description of flexible valves, including useful data on their application.—Farris Flexible Valve Corp., 400 Commercial Ave., Palisades Park, N. J.

Gasket Cutter—A versatile tool for cutting round gaskets from asbestos, rubber, fiber, or cork is described in Bulletin 140.—The Garlock Packing Co., 409 Main St., Palmyra, N. Y.

Bituminous Fiber Pipe—Catalog No. 307 describes "Orangeburg" pipe and fittings for drainage and house sewer use.—Orangeburg Manufacturing Co., Inc., Orangeburg, N. Y.

Coagulant Aids—Information on coagulant aids is available in a recently released booklet on the subject.—Hagan Chemicals and Controls, Inc., Hagan Building, Pittsburgh 30, Pa.

Compressors—Bulletin Form 3207 describes diesel engine compressors for large air requirements.—Ingersoll-Rand, 11 Broadway, New York 4, N. Y.

pH Electrodes—Bulletin 86-5 features electrodes for laboratory and portable pH meters. The material is presented in simplified chart form; indexed and illustrated.—Scientific Instruments Division, Beckman Instruments, Inc., Fullerton, Calif.

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tions, coil filters for sludge dewatering, water and sewer pipe joints, and utilization of sewage plant effluents.

Annual Meeting

The Annual Meeting of the Oklahoma Water, Sewage and Industrial Wastes Conference was held in conjunction with the Water and Sewage Short Course.

The following officers were elected to serve during 1957–58:

President: C. R. Holden, Tulsa.
Vice-President: A. C. Lock, Jr., Claremore.
Secretary-Treasurer: H. M. Crane, Oklahoma City.

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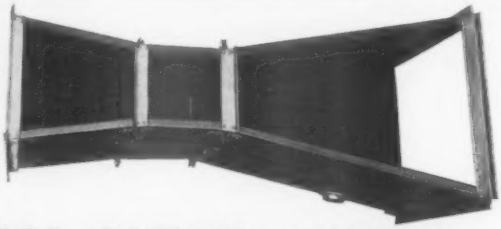

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(Continued through page 166a)

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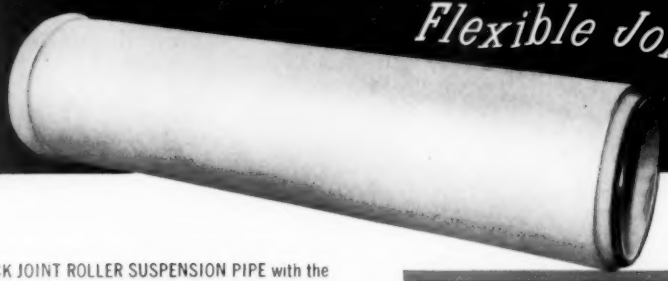

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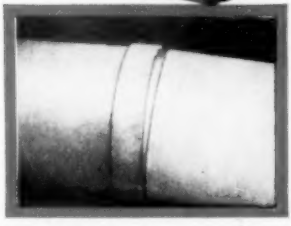

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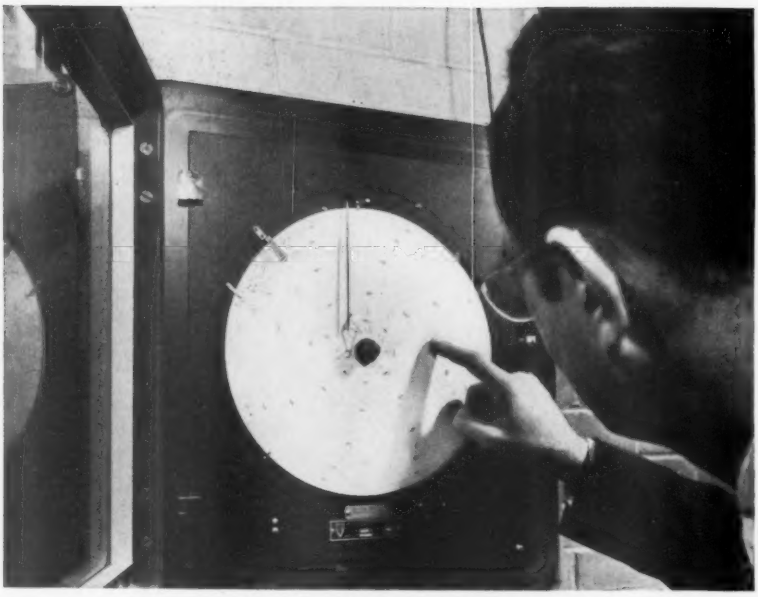

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